THE REGIONAL BALANCE OF MAN

An Ecological Theory of Population

Sir William Meyer Foundation Lectures, 1935-36

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PREFACE

As early as 1925, I pleaded for incorporating the materials and methods of plant and animal ecology into economics, and in the treatment of economic and social evolution stressed the reciprocal adaptation and mutual helpfulness of plants, animals and men in a common environment.[1] In my *Regional Sociology* (1926) I defined the scope of human ecology as a comprehensive science of balance of plant, animal and human communities which are systems of correlated working parts in the organisation of the region.[2] Man's response to regional factors is not individual but collective. It takes the form of a group response in which the solidarity of all living things is involved, and thus comes into the domain of Social Ecology or Synecology. Social Ecology comprises three distinct lines of study: (*a*) The study of ecologic adjustment of the arts of living, of racial, economic and cultural adaptations and the classification of economic systems, social types and cultural zones. These provide the theoretical basis of regional economics and sociology, of all studies in regional consciousness, art and culture. (*b*) The study of a natural balance, albeit a shifting one, of the entire ecological complex comprising different parts of the living and non-living world. This furnishes important clues to the problems of returns and population and of conservation of resources, plant, animal and human. It imports from modern synthetic biology into economic and sociological analysis the conception of "whole", which is more than the sum of its parts. Both the ecological equilibrium in which the oscillations due to changes in external conditions compensate one another on the average and the ecological optimum, which represents the position of sustained maximum economy, point the way towards a better under-

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1 *Borderlands of Economics*, p. 228.

2 *Regional Sociology*, Chapter on Human Ecology, pp. 83-90.

standing of technological equilibrium in economics than the prevalent concepts derived from mechanics. Culture implies not merely pressures, adaptations and balances but also change. And thus a third line of social-ecological research is distinguishable, *viz.*, (*c*) the study of social gradation, mobility and distance and its effects upon individuals and upon the configuration of culture as a whole. In the hands of the American ecologists like Park, McKenzie, Burgess and others, it is this last branch of ecological investigation which has been stressed. They are fundamentally interested in the effects of position and spatial spread on human phenomena. In the changing social world of America—a region of high mobility and squandered resources—different types of social phenomena have been found correlated with the gradient of mobility of population as indexed by various statistical data. From American Human Ecology is accordingly emerging a scientific classification of social phenomena on the basis of such statistically expressed entities as social status, social friction, occupational mobility and social distance.

The lines and methods of human ecological investigation adopted by me have been somewhat different. These include of course the analysis of patterns of spatial distribution of population and of social and economic classes and occupations. For it is in the East that these latter are most stereotyped by geographical resources and ethnic traditions, and are also to-day being most quickly transformed by the forces of the new individualism and population pressure. But I have laid greater stress on the broader scientific aspects of Social Ecology as the comprehensive science of the vital balance and solidarity of the region. The laws, structure and processes of population here subserve the more comprehensive laws of ecologic balance and inter-change.

The study of population thus considered in these lectures becomes Social Ecology; the movement of numbers is treated as a phase of constant transformation of the dynamic relations between different parts of the life-community in the region. As the social or cultural order has become inextricably woven within the skeleton of the

ecological order, the rate of change of human numbers profoundly affects man's subtle and intimate inter-relationships with the entire ecological organisation, determining his struggle and selection, his standard of living and sustained biological balance. Through competition, and the consequent specialisation and segregation of functions, groups and individuals, the population process also governs the shifting relations between individuals, and between occupations and classes in the perpetual struggle for position, status and power. From the point of view of Social Ecology not merely the biological solidarity of man and region, but his entire cultural situation are implicated in the phenomenon of population. More and more we have to move towards the *gestalt* outlook in economics and sociology. Nothing contributes more towards this than the transformation of the foundations of economics on the established ecological principles of relationship.

Human Ecology defines society as man's response to an increase of population. Density transforms a loose agglomeration of families and hordes into society by improving division of labour and social organisation and the transmission of the social heritage. On the other hand, society everywhere arranges its density, spatial distribution, occupation and social stratification, so as to fit harmoniously into its region. The standard of living, the use of wealth and economic power, the pyramidal pattern of social control and distance are mechanisms helping population towards maintaining an average stable abundance. The individual's location, possession and power, his economic and social status are all phases of the collective adjustment to the region. For five-sixths of the human race, dependent mainly upon agriculture, man's ecological complex, including his use of the land, his toil and dietary, determines his density, form of property and economic and social alignments. For half of the race subsisting in South-eastern Asia on 2 to 5 acre holdings, and with hardly any industrialisation to mitigate materially the pressure of population on the land, the laws of sustained ecological balance and of vital inter-change and circulation of the region are more important than the laws of division and

specialisation of labour. As a matter of fact the crowded regions of Monsoon Asia are more appropriate for an ecological analysis of man-land relations, and for understanding the laws of optimum returns and population than the relatively new and industrialised countries of the West. The laws, structure and balance of population can best be deduced from regions of heavy and persistent population pressure. Here we find both the closest social adjustments and the most vivid ecological and vital consequences of disharmonious increase of population. In the Western industrial world the development of machinery and world trade, based on mass standardised production, and the excessive accumulation of wealth in the hands of the capitalistic class have brought about a phenomenal a-symbiotic increase of population and an exceedingly precarious social organisation, which have remained acute misfits. In industrial equilibrium, as in ecological equilibrium, the rate of circulation of necessities for each part of the ecological complex preserves a rhythm and harmony. Ecologic disbalance and break-up follow when any part of the life-community shows a-symbiotic multiplication and excessive exploitation of limited resources. Modern capitalistic production shows a disequilibrium because the entrepreneurial classes, brought into existence by the necessity of central co-ordination and control, have appropriated from the industrial structure an income, which exceeds the amount that they have opportunities to invest and inclinations to spend, and consequently checked that vital circulation of services and goods which keeps alive the capitalistic system. But the ecologic and economic disequilibrium is no less profound in the hitherto stable agricultural civilisations.

The study of population becomes a science only as Social Ecology, *i.e.*, by linking the facts of economics with the facts of ecology in different regions and cultures. It has also its applied side. If it be true that society is an ecological experiment, the study of population also calls for appropriate family attitudes, social habits, and economic organisation that maintain a steady vital interchange and prosperous, sustained numerical balance. It

is primarily the ecological planning of numbers that will determine what types of culture will survive or fail on the earth.

Some amount of repetition has been rendered inevitable as these lectures had to be delivered from day to day and to students of economics mostly unfamiliar with ecological study and treatment. The same ecological concepts sometimes have been reiterated from different approaches and fields of economic life.

Some materials and methods of this survey were presented recently by me in courses of lectures delivered before the Universities of Cambridge, Oxford and Liverpool in England, the Universities of Cologne and Vienna in Europe and the Universities of Chicago and Michigan and the Columbia University, New York, in the United States. My thanks are due to Professors Park, McKenzie, Odum and Burgess with whom I had several days of valuable discussions on ecological methods and their applications generally during my recent visit to America. I wish also to express my thanks to friends and colleagues who did so much to make my stay in Madras an enjoyed occasion. I am grateful to Mr. B. C. Gupta, B.A., for a full and valuable index. My acknowledgments are also due to the editors of *The Sociological Review, The American Journal of Sociology, Sociology and Social Research, Social Forces* and the *Proceedings of the International Congress of Population* in Rome, Berlin and Paris for permission to reproduce several articles which appeared in these scientific publications. Finally, I have also to acknowledge the assistance of the Madras Law Journal Press whose patience I sorely tried during my absence in the West.

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CONTENTS

INTRODUCTION.

In the following lectures I have attempted to apply to human society the same principles and laws which have been applied recently to the distribution and succession of plants and animals in different regions. In my *Regional Sociology* I have already given a conspectus of the classification of social types and institutions under various regional conditions. If sociology would undertake the definition of the various social types and the principles that govern them in different regions, the science would be less sectional and the present hiatus between social history and social theory on the one hand, and the danger of the substitution of cultures on the other, would be obviated.

Sociology in its early days came under the spell of biology. The older biology was, however, mostly systematic and classificatory. It is only recently that regional surveys of plant and animal communities have been undertaken, and these have inaugurated a new branch of biology, namely, ecology, which is not only profoundly affecting the methods and materials of biology, but also is found to be of enormous significance in the study of human groups.

Perhaps the most important contribution of ecology is the idea of the region as an intricate network of interrelations. The region exhibits a complex pattern of adaptations between the environmental factors and the plant and animal communities, including human societies.

The mutuality of adaptations, which are endless and ever shifting, gives us the picture of the total situation as a configuration like the *Gestalt* of Wertheimer, Koehler, and Koffka. The change of any factor of the environment, such as a spell of drought or a cold winter, gradual transformation of landscape due to maturity of the river

system, and change in drainage and texture of soils, brings about a complete change in the *milieu,* in which plants, animals, and humans find a new equilibrium through natural biological processes. Each new mode of adjustment, whether the change of the type of vegetation from woodland to shrub and bush, or the succession of wet by dry crops, or, again, the construction of wells and canals, implies an entire transformation of the situation in which man, with the rest of nature, undergoes a change in life. Similarly, when man introduces new cultivated plants, animals, or insects into the region, or exterminates the carnivores and allows the rodents to multiply as in every old human settlement, or, again, changes from shepherding to agriculture and from agriculture to industry, he remakes the region and revises its organic constitution.

In the older sociological speculation man was yet treated as a part of nature, but in a frankly deterministic fashion; his plans and endeavours were conceived more as extraneous forces than as phases of the ecologic complex interwoven with the rest of the environment. Man is part and parcel of the process by which the balance of the region is maintained or shifted, and the process is ever continued in see-saw fashion, now in favour of man, now definitely against him. In this process the entire life of inorganic nature is involved, though it may be initiated by some slight human action that sets in motion a series of processes which may conserve or upset the order of nature. It is true that such disturbance of the balance of nature is sometimes inevitable for the continuity of human communities. But often such disturbance is casually and carelessly brought about, or increases cumulatively through man's interferences continued for generations until it saps the roots of the region's life and engulfs man in the common doom of the region.

Man's skill and efficiency too often have been displayed without regard to the essential biological fact of his solidarity with nature. With better appreciation of

this solidarity, the conservation of natural resources will be raised from an economic creed to a biological faith. The permanence of civilization depends chiefly on man's intimate understanding of and co-operation with the totality of the region's forces, including not merely climate, soil, and topography, but also the associated vegetable and animal life. In a new country man can with impunity disobey the order of nature, mainly because of the large margin and variety of nature's reserve; but, when man has become established in his adopted region, his security and well-being will be found to rest on maintaining the balance and rhythm in the organic and inorganic nature that forms his environment. Many are the instances in which man, having multiplied in large numbers in an old-established region, has sought an increase of food-supply by indiscriminately destroying forests, transforming pastures into cultivated fields, reclaiming marshes and low lands, exhausting the soil, and robbing the sub-soil water. These activities have often been pushed to the extent of upsetting the equilibrium between the factors determining the climate and hydrographical conditions of the region, thereby incurring agricultural disaster, and ruin of ancient civilizations. The law of diminishing returns is part of a wider law of the exhaustion of the store of nature, prefaced by gradual and advancing sterility and denudation, when man, through shortsightedness, ignorance, or selfishness, destroys the established cycle of the region's life-processes. Not merely land and water thus may become limiting agents in production, but also the interference with the old-established arrangements of vegetable or animal aggregations may be disastrous. Throughout the course of evolution, the interrelations of organisms have become more and more intricate and complex. Thompson observes: "Many of the simpler animals are related to their environment—whether for food, oxygen or anything else—in a very generalised way; but evolution has meant an increasing specialisation in the business of exploiting." As organs and functions have become more specialised and

complicated, so the balance of relations has become finer and more intricate. Animals are linked with one another in elaborate and complex arrangements of food cycles, and their food and habits show mutual interdependence as well as specialisation. In a progressive food chain the modes of exploitation have become diverse and subtle. The balance has been more difficult to maintain the more the circle of an animal's life has intersected other circles. When we come to man, whose mode and extent of exploitation know no limits, the danger of disturbance of the balance of the region is constant and cumulatively pressing. To give instances, man's successful farming and forestry depend on turning to his own use the ecologic succession of plant forms, and the natural arrangements of eating and being eaten among the beneficial and injurious animals, such as small mammals, birds, and insects, and the reproductive interrelations as exhibited, for instance, in the pollination of flowers by birds and insects, or the scattering of seeds by fruit-eating birds and herbivores. Man, in the course of agriculture, grazing, and forestry, changes his own habitat as well as that of his animal competitors, destroys them or converts them either to allies or enemies in various complicated tangles in the web of life. His cold-blooded rivals, insects and plant pests have often thwarted his advance, especially in the tropics, killing both men and domesticated stock by thousands; while the tireless micro-organisms of the under-world adapted to every soil, climate and crop play no small part in determining the fortune of his agriculture. Nearly all soils contain nitrifying bacteria capable of living in symbiosis with leguminous plants, mere weeds. By maintaining a proper balance between plants and bacteria under any given condition of soil, climate or crop rotation, man may secure for the next crop a store of nitrogen considerably in excess of that before possessed by the soil and thus make agriculture possible without soil exhaustion. Successful agriculture is, indeed,

indissolubly bound up with the problems of proper handling of bacteria in relation to soil and plants, and of nitrogen, iodine and minerals used as food for the draught animals, as food for the grasses and crops and as organic manure. Where the soil and vegetation are deficient in iodine, not merely the cattle but also humans would not thrive. Stock-raising industry in large tracts in the west of America took a new turn when this was understood and iodine compounds were added to the drinking water supplied to the cattle. The treatment of goitre and generally speaking of thyroid deficiency, which leads to a condition of permanent abnormality and disease now rests on the supply of an adequate amount of iodine in the diet, and the use of the natural thyroid-extract or the artificially prepared thyroxine. In Switzerland it is now illegal to place on the market salt that has not been iodised to the prescribed degree.[1] In all centrally situated countries or tracts of land where the distance from the sea accounts for inadequacy of iodine salts in the soil and in vegetables, milk and other products raised, the problem of securing normal thyroid secretion both for live-stock and humans is too important to be overlooked. We, therefore, find that agriculture, insect control, animal husbandry and human nutrition are all bound together in mutual dependence and influence in complex ways. The exhaustion of minerals in the soil, the deterioration of grass and cereal and the ravages of insects have been potent factors in the vicissitudes of civilisation. Man's social economy is thus inter-laced not merely with soil, oxygen, water, temperature, etc., but also with the organic setting of the harmonious vegetable and animal communities that have arrived at a more or less stable equilibrium. Therefore the laws of economics or sociology have to subserve the more comprehensive laws of the balance of life.

(1) Parsons: *The Materials of Life*, p. 226.

The laws of the balance of life are laws that it is necessary to obey. To go ahead impulsively and incautiously, without giving adequate consideration to the intricacies of the great *Systema Naturoe,* may subserve economic ends temporarily, but if continued leads inevitably to punishment. Such disregard of final results and concentration on the immediate practical ends is easy in the case of an old region, where the economic struggle has become intense owing to pressure of population. It is a curious paradox that, where man has torn the web of life, nature seeks to repair it through a reduction of the population to numbers that the ecologic balance may permit. For example, the sieve of nature eliminates asymbiotic growth of a community when it threatens to disregard her rhythm and balance.

Such loss of balance we hardly find in newly settled parts of the earth. Yet even new countries by multiplication of population sooner or later are faced with the problem of exhaustion of the natural store. Some again postpone the evil by exploiting the backward regions of the earth through the plantation system, or commercial agriculture, which means intensive exhaustion of resources, both natural and human. Many of the industrial countries of the West have adopted a scale of social and industrial living, which has little reference to the resources and possibilities of the regions themselves. This lack of balance between the standard of consumption and the production of food and raw materials has been the chief cause of the present spendthrift use and unfair distribution of the world's resources. Industrial civilization cannot thrive for long on an unstable balance between man's demands and the region's yields, which needs to be maintained by improvident use of resources in men and materials in other parts of the world.

Man's adjustment to his region so far has been dictated mainly by this instincts, and by the traditions of his race. Industrialism and overpopulation make it impossible for nations to pursue the policy of *laissez-faire* in regional adaptation without calling forth nature's

penalties of decay, disease, and death. Science must now comprehend the manifold web of relations between human life and organic and inorganic nature. It must also reveal the relationship of cause and effect between man's activities and the subtle and remote phases of transformation in nature's life processes. Insomuch that man scientifically envisages the threads which the region weaves around him, binding him with climate, land and water, and with plants, animals, insects and bacteria in a sequence of actions and interactions through generations, his works and products will be more in tune with the rhythm of the environment, and his civilization will not be a fleeting episode, as it has often been in the past, but will be ever new, ever fashioning for its children new ties with the rest of creation like its matrix, the mother earth itself. In his reaction to the region, the material background of his culture, as well as to that of his fellow beings in his social relationships, institutions and ideals, man will thus continue to fashion newer and subtler linkages, so that both the Kingdom of Nature and the Kingdom of the Spirit will exhibit a solidarity that will be at once organic and spiritual.

CHAPTER I.

HUMAN ECOLOGY, THE SCIENCE OF POPULATION BALANCE.

Ecological approach to Sociology.—Ecological methods are applicable to many branches of sociology. They may be employed, for instance, in the study of social evolution and adaptation. The works of the anthropo-geographers, Ratzel and Vidal de la Blache, have contributed to promote among various subsequent writers the regional, or what has now expanded into the ecological, outlook. The intensive methodical surveys of the Le Play school, particularly in France, clearly emphasise the importance of the physical environment in its relation to society, and especially in its effects upon occupation and family life. In the same country both Brunhes and his associate Vallaux have studied the physical landscape in so far as it has influenced human destinies, and also its exploitation or deformation as the measure of the power of human societies. Their influence has extended much beyond their country in eliciting meticulous local and regional studies. The German school, exemplified by Schluter, Michotte and others, has stressed what has been called the anatomy and physiology of spaces or landscapes with a view to show the development of the cultural out of the natural landscape. Professor Patrick Geddes and his school, working both in Great Britain and recently in France, are not only using the regional survey method as a comprehensive tool of social study in definite regions and cities, but also have evolved a simple mathematical scheme for presentation and co-ordination of their data. In America, Huntington has studied particularly the effects of the climatic factors on the distribution of human energy, and the opportunities and limitations of civilisation in different environments. The culture-area concept in the hands of Wissler, Kroeber and Herskovits, though confined to anthropological data, also has influenced sociology, notably through the writings of Willey.

Through all this development of social theory the ecological approach is gradually assuming significance. The conception that man and the region are not separate but mutually interdependent entities, plastic, fluent, growing, has been emphasised in my *Regional Sociology*. It outlines a programme in which the region and the web of life within it are made the subject of a new division of sociology. Man's mastery of his region consists not in a one-sided exploitation but in a mutual interchange, which alone can keep alive the never-ending cycle of the region's life processes. The region also is not a passive entity but a living organism which exhibits the harmonious working of different life systems, such as the vegetable, the animal and the human worlds. These mutually influence one another, establishing some kind of balance. Ecology, the science of the balance of species, the comprehensive physiology of life in all its forms, not only throws light on social origins, but also gives the clue to an understanding of the regional balance of population.

POPULATION DENSITY A CLUE TO ENVIRONMENT.—The interrelations between animate and inanimate nature, and between the systems comprised within the former, in fact must be more clearly analysed in the study of social causation. Thus, along with the effects of climate, topography, soil and resources on man and his occupations, social institutions and ideals, and the effects of human communities upon one another, we have also to consider the relations between human and vegetable and animal communities, representing as they do correlated working parts in an ecological complex. Man is to be conceived, so far as his community-reaction to the environment is concerned, in his different expressions of population density, and his varying efforts to maintain it with plants and animals that compete or co-operate with him for a place in the sun and on the land. The density of population is a measurable quantity like the forces of the environment, such as temperature, rainfall, or soil; its increase or decrease responds to natural factors, and may be subject to similar methods of study

as are applied to the succession of plant communities or the number and distribution of animals. Sociology accordingly gains in exactness through the use of the quantitative method, when the ecological relation of the human community to the environment servcs as pointer reading.

REGIONAL BALANCE.—There is a balance between the natural and the vegetable and the animal environment, including the human, in which nature delights. It is maintained by chains of actions and interactions, which link man with the rest of his living realm, reaching up and down and all around as his invisible biological and social destiny. Such balance assumes great significance in old countries like India and China. Here we can discern, especially in the mature, densely peopled plains, every stage of the process by which the regional balance is kept stable and how it is upset both by natural fluctuations such as are caused by cycles of rainfall or changes of landscape and river, or by long continued human actions such as the destruction of forests, conservative agriculture and artificial interference with natural drainage.

INTERFERENCE WITH NATURAL BALANCE.—Plant and animal ecology has shown the adaptation of plant and animal associations to the region, and also to one another. Says an ecologist; "The animals and plants of a region form a vast complex in which every organism affects every other directly or indirectly, and is in turn affected by all the others. Further more, all the organisms are influenced by their environment, and in turn affect the character of the environment. All the organisms are bound up with one another in an intricate network of interactions which the mind can only partially comprehend." An important section of plant and animal ecology deals with the disturbances which human and animal populations bring about in the natural ordering of the array of different plants and animals formed in a given region at a particular time. Thus the ecological succession of plant and animal communities, and the interplay of the forces

of the region and the animals and plants as well as of the biotic factors responsible for their development or retrogression have now come to the forefront. In wild nature an abundance of rabbits leads to the supersession of pine trees by heather and of heather by scrubby rushes, and of rushes by a mere carpet of grass. A heavy pressure from the small rodents as well as prairie dogs or kangaroo rats, when they form large colonies, similarly leads to the retrogression of vegetation, and the initiation of secondary series in the new world. Similarly overgrazing and trampling by man's domestic stocks result in the complete destruction of the vegetable cover and the appearance of perennial or seasonal weeds. Man by burning the forests, and cleaning the ground for farming sets up a train of primary or secondary sequences in which an entire series of plant species and communities are implicated.

MAN'S ENTOURAGE OF PLANTS AND ANIMALS.—A notable instance of such complex sequences is found in the effect of man upon predatory animals. As population increases, and the frontiers of cultivation extend the carnivores are ruthlessly exterminated. One result is that the rodent population enormously expands with a corresponding decrease in the yield of grazing range or cultivated field. As Weaver and Clements observe: "The destruction of predatory animals which appears to be a simple and beneficial interference tends to defeat in some measure the very purpose it was designed to promote,—the greater production of cattle and sheep." Normally the region shows a definite sequence of the succession of plant and animal communities.

Man, by brand tillage, forest clearing, indiscriminate stock-grazing, and intensive farming, thus alters the conditions of the environment to the extent that a large number of plants and animals fail to survive this onslaught. He has, again, artificially improved and fitted plants to survive particular conditions of climate and soil and imported exotic varieties from similar regions, thereby continually improving the yield of his cereals and extend-

ing the frontiers of cultivation. The plants which he does not tolerate are called weeds. These are ruthlessly destroyed and some of them have become man's pauperised dependents. Many weeds, again, are imported from outside as a result of man's carelessness. It has been estimated that more than half the weeds in America have been imported from Europe by the continual shipment of agricultural and horticultural products.[2] A few prickly pears introduced into Eastern Australia, and water hyacinths into the delta of Eastern Bengal both as botanical curiosities have now covered thousands of miles and become a serious menace to agriculture and communications. The intentional or unintentional introduction of exotic plants and domestic animals profoundly affects the flora and fauna of the region. A new plant and animal association is established but it will be harmonious if the time that elapses is adequate for the working out of the forces of bio-economic equilibrium. J. A. Thomson quotes the observation that in the mountains and forests of Central Europe every spot that has been used as a human abode can be identified by the plants that grow there and the animals that visit them, long after every trace of man's habitation and handiwork has disappeared.[3] A large number of animals, some enemies, some allies, sometimes have been either entirely exterminated or greatly reduced in numbers. On the other hand, in the broken balance of nature man creates more favourable conditions for certain species of animals than in wild nature. In his cultivated fields, notably in areas where one particular crop like cotton, wheat or potato is grown over a vast expanse man has nurtured through the supply of unlimited food, hordes of insect pests, parasites and fungi which it is difficult and often impossible for him to combat.

MAN'S WILFUL OR UNCONSCIOUS INTRODUCTION OF PESTS.—Modern agriculture demands the cultivation,

(2) Weaver and Clements: *Plant Ecology*, pp. 107, 394-95.
(3) *The New Natural History*, Vol. I, p. 180.

year after year, of large artificial areas of single crops. This has accordingly provided the insects which eat these crops with a heaven-sent opportunity to obtain unlimited food without effort and so to increase with unprecedented speed. The cotton boll weevil was an obscure beetle living largely on wild hibiscus until the appearance of vast cotton fields relieved it from the necessity of searching and competing for food. The Colorado beetle was a harmless eater of the Deadly Night Shade of the Rocky mountain regions until American pioneers laid a trail of cultivated potatoes for it to follow. Within twenty-five years the beetle reached the Atlantic coast. And insects have by no means ceased to change their habits. The wheat-stem saw fly is a case in point. Previously the grub tunnelled in the stalks of certain grasses, and attacked those grasses only. Gradually it spread rapidly westwards through the Canadian wheat fields, and in 1926 did £2,400,000 worth of damage in the State of Saskatchewan alone.[4] It may be mentioned in this connection that such change of food-habits reacting unfavourably on man is not confined to insects. The instance of the kea parrot of New Zealand is often adduced. When sheep-runs began in New Zealand, the kea parrot gave up berries, grubs and insects and began to tear the loins of the sheep which they found in abundance, indulging in the pleasures of carnivores. Similarly in Africa the birds known as ox-pickers were adapted to picking parasites from the tough hides of rhinoceroses. When domestic cattle were introduced, the birds began to tear away with their powerful beaks the backs of the oxen.[5] Thus the introduction of new plants and animals turns harmless creatures into pests. "Agriculture which has everywhere meant the unnatural massing of single kinds of plants and animals has not only given new opportunities to the fungi, bacteria and protozoa that are the causes of most animal and plant diseases but is an open invitation to insects." This is notably

(4) Walter Eliot: The Economics of Insects, *Contemporary Review*, August, 1930.

(5) *The Science of Life* by H. G. Wells, Julian Huxley and G. P. Wells, pp. 679-680.

so in the tropics where insects are more abundant and their life runs quicker.

INSECTS AS MAN'S FORMIDABLE RIVALS IN THE STRUGGLE FOR DOMINANCE.—Agriculture in the tropics is accordingly mostly an uphill task of controlling plant and animal diseases and fighting harmful insects. The development of means of communications also facilitates the spread of insects and animals from one country into another. It has been estimated that from among 73 of the worst insect pests of the United States, 37 have been introduced from foreign countries; of these latter most of them have entered America unaccompanied by natural enemies that help to keep them in check in the lands whence they originally came.[6]

On the other hand, one of the effective methods of fighting the insect menace, known as biological or natural control, consists in the search for parasites and predators in likely parts of the world and their use for the purpose of ensuring higher mortality among the pests. Although man may have destroyed the giants among his enemies in the animal world, he also by his own methods adopted in civilisation has multiplied his invisible, and more deadly foes. Insectivorous birds are largely instrumental in maintaining food production. It is estimated that a pair of fly-catcher will destroy 2,500 flies a week and a great titmouse will catch 8,000 to 9,000 insects chiefly caterpillars. Man's indiscriminate destruction of birds, which destroy countless numbers of noxious grubs and other agricultural and garden pests, increases the depredations of insects. Similarly, the ravages of rats, mice, rabbits, squirrels and sparrows are instances of the abnormal increase made possible by man's interference in the animal economy with the old-established arrangement of eating and being eaten, and his mass production of food for them. On the other hand, man has now learnt to fight unwanted animals by means of biological control, *i.e.*, by discovering the natural enemies of animal pests and

(6) A. D. Imms' article on Entomology in the *Encyclopaedia Britannica*, 14th edition.

releasing them to work death and destruction in a natural way. With a large number of insect pests of plants this has already been done most successfully, and attempts are being made to eradicate or hold or check noxious weeds by insect and fungoid armies marshalled by the scientist. The pest-control biologist should, however, move very cautiously. Zoologists have made us familiar with the interesting examples of the introduction of the sparrow into the United States to check the ravages of the destructive elm-tree caterpillar, of the rabbits into Australia to increase the food-supply, and of the mongoose into Jamaica and the Antilles to combat the menace from rats. In all these cases man had ample reasons for repenting of his folly. The sparrows ate ripe corn as well as caterpillars; the rabbits ate more food than they supplied; the mongooses turned their attention to lambs, kids and piglings when their supply of rats and mice ran short. Bacteria or germs have been used against noxious plants and insects as well as against rats. Many types of bacteria and fungi causing disease, however, prey indiscriminately upon beast and man, just as there are many kinds of insects which could be used to stamp out noxious plants, were it not that they would attack crops also. "The biologists' difficult task is to drill his miscropic mercenaries into ordered platoons which will fight one enemy, be it rabbit or rat, baboon or bandicoot, and then rest content on the laurels of that victory".[7] It is on the whole true that the instances in which man has caused an increase of animals in the new man-made environment are confined to the pests. On the other hand, these pests may do more harm than in wild nature simply because domesticated stocks, men and crops are found in mass in the new environment. To quote a zoologist: "In the disturbed balance of nature, man must divide the spoils with those creatures whose very existence has been made easier by his practices. We view a protracted struggle between man and other animals, all competing for

(7) Capt. William Hichens: Unwanted Animals: A World Problem: *Discovery*, April, 1930.

supremacy with only a relatively small margin of the advantage in man's favour. This struggle is as old as man, and will doubtless continue as long as man and the insects stand as the two pinnacles in the evolutionary process."[8]

EFFECTS OF MAN'S SUBSISTENCE, HEALTH AND LIVING CONDITIONS.—The study of the so-called biotic and especially human interferences in ecological succession is thus gradually being supplemented by the recognition of the harmful effects of man's unskilful and improvident interference with his organic *milieu* on his food-supply, health and living conditions. Elton is right in his criticism that human ecology has been concerned almost entirely with biotic factors, with the effects of man upon man, disregarding often enough the influence of trees and animals, land and water. Owing to the fact that most workers in this subject are themselves biotic factors, an undue prominence has been given in history and economics to these purely human influences. The ecology of population will not only stress the importance of the intimate ecologic interrelations of man, so grudgingly recognised by him, but also in its applied aspects will demand his close alliance with the entire range of ecologic forces, his co-operation in the conservation of the land, in the use of water, in the management of forests and rivers, as well as in the domestication and use of his live stock and control of insects, bacteria and parasites. A disregard of such co-operation, which is at once nature's law and human wisdom, would spell man's social disaster. Such disregard often comes from man's folly, imprudence or selfishness. Its effects are both swift and devastating when he multiplies in numbers so large as to make him indifferent to the needs of his future generations, a habitual and confirmed offender against the land, trees and animals, which constitute the region from which he must obtain subsistence.

(8) Van Cleave: Our Changing Fauna, *Transactions of the Illinois State Academy of Science*, February, 1929.

MAN'S DISHARMONIOUS INTERFERENCES.—Man appears periodically to bring ruin upon himself by living disharmoniously in nature, whether in arid tracts or in fertile valleys. He denudes the mountains, depletes the pastures, and exhausts the soil and the subsoil water-reservoirs. By so doing he deforms the landscape and alters the conditions of soil, vegetation and water-supply, making it more and more difficult for successive generations to wrest a living from a region however bountiful it might have been in the past. But the danger is not merely economic. The older the settlement, the more artificial it is. Surface tillage, defective soil and drainage, mere abundance of food and waste, and over-crowding of men and herds favour insects that destroy man's crops and herds and transmit fatal diseases from man to man, or from animal to animal in an unbroken cycle of insect life and growth. "In a country where the conditions are settled, each species of insect is subjected to a certain fixed average percentage of parasitism, which in the vast majority of instances, and in connection with numerous other controlling agencies, results in the maintenance of a perfect balance. The insect neither increases to such abundance as to be affected by disease or checked from further multiplication through lack of food, nor does it become extinct, but throughout maintains a degree of abundance in relation to other species, existing in the same vicinity, which, when averaged for a long series of years, is constant."[9] In the broken balance of nature where man has introduced artificial conditions for his own benefit, or as incidental to his dwelling for centuries in a given area, he has often indirectly favoured some species of insects, which have multiplied at his expense in much larger number than they could in the original state of their environment. These have now become man's most formidable rivals in the struggle for life. The disturbance of the balance of nature is accordingly often the natural result of the antiquity of a country, where man has multiplied in larger numbers than its ecological balance permits.

(9) Cited in Ealand, *Insects and Man*, p. 303.

CHECKS TO ANIMAL NUMBERS.—Nature, again, has her own remedy. In the case of animals, nature has evolved a method of regulating numbers through the complex system of food-chains and cycle of malignant epidemics, as well as through adaptive habits and other characteristics keeping them at a certain equilibrium density; she has also an analogous system for human communities. Among social insects increased co-operation and division of labour between members of the same species usually have the effect of enabling a denser population to exist on a given area and this fact has a direct bearing on the problems concerning the numbers of the more specialised insect communities. On the other hand, among birds and mammals and some of the insects division of labour between the sexes has become mixed up with more or less elaborate systems of territory which are required for the proper provision of an adequate supply of food for the developing of the young. A train of habits connected with nesting, courtship and watering as well as the amount of food available in the ecological area from season to season, determine the size of the territory or the hunting ground of the higher mammals.

We see here the beginning of super-imposition of clearly discernible psychological factors on the mere biological factor of food supply as limiting animal numbers. Thus the spacing out of families whether in well-peopled hives or in nests and territories, colonies and communities acts as limiting factors to numbers. Besides these economic and social psychological factors physiological sterility of certain members of the species as well as regulation of larval feeding or internal secretions are the methods by which the prolification of certain species of social insects which live in large aggregations is controlled. Most species of insects, however, as soon as they exceed an average density are kept down by the multiplication of birds or other predators. In a short time they are reduced to their normal numbers, and the balance of nature is restored. As insects multiply excessively, the birds and mice feed on them more voraciously; as the mice and birds reach abnormal numbers, the hawks, owls, and other

carnivore enemies migrate to the infested area and hunt them continuously. Thus a continuous system of food chains brings about a balance of numbers, albeit a swaying one. Thomson remarks: "Each area has its own particular association of plants and animals that are suited to the conditions, and that can live together, all finding sufficient food, often preying upon, but never exterminating one another, each species, not without effort, keeping its foothold, but not usurping more than its due place in the general harmony. Thus the balance is not the same all the world over, but varies in every area according to the conditions of climate, soiling and surroundings. Even then it is not fixed, there are constant fluctuations, for the web of life is still a-weaving, and its pattern is constantly changing."

Elton's conception of niches is of great importance in the study of animal numbers as it makes clear that in each animal community, there are a great many occupations or jobs as there are in the human community, each niche being filled by a particular species.[10] In different habitats occupied by other animal communities the same niches may occur but the actual species fitting them are different in most cases, though habits, numbers and size are to a large extent similar. The conception of optimum density as applied to animals, like that of territories in species of birds, and of niches in animal communities, is an elastic one. An apparently small cause changes the size of territory, and the niche of the animal, and hence the equilibrium numbers of animals vary according to locality and to economic pressure. Nature, however, sooner or later corrects matters again, and the optimum numbers are restored. Where the natural predators fail to thin out the pack or swarm of animals such as mice, rats, lemmings, deer and antelope, bacteria or protozoa take up their role decimating the animals by thousands in a short period. Almost all the vast plagues of gnawing or herbivorous mammals in tundras, steppes or woods end in fulminating epidemics which spread with extreme rapidity and reduce the popula-

(10) See Elton: *Animal Ecology*; also article in *Encyclopaedia Britannica*, 14th edition.

tion far below its average density. Conversely, costly measures devised for fighting the plague are infructuous if Nature is not given a free hand to combat these outbursts by her own instruments. The malignant epidemic, however, does not persist, and ceases to be a scourge when the density of population decreases, the rate of circulation of the parasites being slackened. Thus both enemies as well as diseases strike out a normal balance of numbers with an ecological area.

SELECTIVE MORTALITY AMONG ANIMALS AND HUMANS.—Man does not form an exception to the forces and methods which operate in the animal world for regulating numbers. Gregarious as the human community is, human numbers do not multiply up to the extreme limit of starvation. For this would hardly differentiate between desirable and undesirable human characters when the year of famine arrives. In the case of sparrows, found benumbed after a heavy storm, it was observed that the birds which survived had certain structural characters which those that perished did not possess. In very unfavourable years many creatures are thus examined on their power of resisting hunger or thirst or extremes of heat and cold. In favourable years, when the numbers of animals are at their maximum, they go through the tests of resistance to parasitic diseases and success in finding out females in competition with other males.

Evidence of discriminate elimination, which is found among animals, when their food supply runs short, does not hold good at least to that extent in the case of men. Thus the human group evolves an indirect method of eliminating numbers. Before it multiplies to the extent of overeating its food-supply, other checks come into operation. A gradual lowering of vitality as well as predisposition to disease, due to increased economic pressure and crowding, lead to increased death rate; while the birth rate also slackens if the population continues for long above its average abundance.

MALTHUSIANISM, UNSUPPORTED BY SOCIAL ECOLOGY.—The Malthusian postulate that population always thus

tends to increase up to the limit of food supply is neither true of animal nor of human communities. For, obviously, it would be an unworkable system for gregarious animal communities in particular, if no margin were left for times of food scarcity, which are bound to recur, and the entire population were liable to destruction by starvation irrespective of individual merits. Thus "gregarious gluttony," which jeopardises the survival of the species, is avoided as a result of the operation of various checks, which either limit reproduction or periodically diminish numbers far below the mean. In the case of human numbers, before an actual shrinkage of food-supply acts as a direct check, although the possibility of it is always present, there is found a lower vitality of the population, that has overstepped the limit of an equilibrium density under static conditions of the arts of production and the plane of living. Recent studies by Elton, Howard, Nicholson and others of animal numbers and mechanisms of their regulation and distribution in distinct ecological areas emphasise the significance of the conception of optimum density, which Malthus and his followers had not perceived. As in the case of animals, men also fluctuate in numbers round about optimum density.

In man as well as animal both below the optimum density and above it the conditions become advantageous to the species; in the case of man, who shows in certain densely peopled agricultural regions a much closer adjustment to the ecological area so far as his arts of production etc., are concerned, the limits of the optimum may, indeed, vary less than in the case of animals. Though the Malthusian check of a malignant epidemic or pestilence is seen to operate among certain animals like the small rodents, which have big appetites and multiply very rapidly, the normal check comes from the prolification of the animals' natural enemies, which prey upon them and keep them to their normal numbers. In man the check from the inclemencies of the weather and natural enemies has ceased to operate; while famine which Malthus regards as the most fundamental positive check operates directly but seldom. Through an increase of death rate and de-

crease of birth rate man appears to reach in a few years his normal numbers again, and thus the balance of nature is restored. In the densely crowded areas of the Ganges plain, the average rural density depends upon soil, climate and agricultural water-supply (rainfall and irrigation); and where this has been exceeded there have been seen an increase of mortality, and sometimes a decrease of birth rate, while epidemic diseases like bubonic plague and malaria have also played their part in restoring the nicely adjusted balance of numbers.[11]

Both among men and animals the chances of infection passing from one to another increase as populations increase in mass. Professor Topley of Manchester has demonstrated this experimentally in artificial mouse-populations which have been studied at different degrees of crowdedness, and the fact is a matter of common medical and veterinary observation.[12] Julian Huxley has shown that in grouse sheer overcrowding brings conditions to a point at which parasites formerly harmless cause sudden epidemics. A sporadic disease breaks out in epidemic form in overstocked grass-lands and woods, occupied by small rodents, mammals and birds as well as in densely packed human settlements. Conversely, an infectious disease dies out if the density of its victims is too low. Sir Ronald Ross has demonstrated that if the population either of mosquitoes or of men falls below a certain density in a given area the proportion of malaria infected individuals will decrease slowly but progressively to nil.[13] Where a disease is spread by a carrier, it is obvious that its incidence will depend upon the number of individuals, animals or men, it can meet. Thus the denser the population, the greater the number of contacts and possibilities of infection and the greater the rapidity of the spread of disease. The fleas of a rat dying from plague

(11) Radhakamal Mukerjee: Optimum and over-population, *Indian Journal of Economics*, January, 1930.

(12) Quoted in *The Science of Life*, by H. G. Wells, Julian Huxley and G. P. Wells, p. 669.

(13) *Ibid.*

and isolated in a jungle would probably themselves die because of lack of hosts, but if the rat dies in the midst of a crowded village some at least of its parasites will probably find new hosts, whether rats or humans, and thus propagate the disease. A dense population whether of gregarious animals or of men affords opportunities to bacteria and parasites in two ways: (1) the abundance of hosts leads to a rapid diffusion of the epidemic. (2) the increase of economic pressure due to abundance of population lowers the general capacity to resist disease. When an epidemic breaks out in the course of migration of animals, there is added a third factor, *viz.*, the strain caused by long journeys under new and unfavourable conditions. Birth and death rates are, to some extent, as much features of ecological adjustment as modes of land utilisation, dietaries, or types of labour.

THE ECOLOGICAL COMMUNITY CONSISTS OF SYMBIOTICALLY GROWING PARTS.—Thus human, animal, and plant communities are subject to similar rules, which maintain a balance and rhythm of growth for all though subject to fluctuation. Each community cannot appropriate more than its due place in the general ordering of life from which nothing can be obtained without influencing everything else. Working symbiotically, they represent interwoven threads of a complex web of life. No one thread can be isolated; none can be snapped or removed without injury to the whole fabric of the life of nature and human society. The warp and the woof of the fabric have become increasingly coherent as organic evolution has advanced. The interrelations of a fig-tree, an earthworm, a rat and a bird are many, but the threads make much more intricate patterns when we reach the social economy of man. Though man often tears asunder the fabric through ignorance or selfishness, social progress no doubt consists in consciously weaving the forces of nature and society into finer and finer patterns of correlation and solidarity. It is knowledge of and respect for the intricacy of the web of life which will guide man to his highest destiny.

CHAPTER II.

MECHANISM OF CONTROL OF NUMBERS, ECOLOGIC AND SOCIAL.

POPULATION PROBLEM.—The growth or decline of human numbers is the most significant phenomenon in society. Yet, in spite of discussions and controversies that have ranged round this problem since Malthus wrote his celebrated essay, there is no subject in sociology which is treated in so unsatisfactory a manner, with so many prejudices and even superstitions. Hugh Dalton has put it mildly in observing that the theory of population is "still full of gaps and ambiguities and still looks intellectually untidy":[1] The problem of population comprises three parts. The first would consist of the study of the causes of the movement and distribution of population. The second would consider the size of the optimum population, the methods of reaching it, and the economic and social consequences of defect or excess. The third would deal with the measures necessary to regulate numbers and the distribution of surplus population, or to improve the quality of the species. Eugenics, ethics, religion and scientific humanitarianism, all co-operate here in finding out practical remedies for the menace of over-population that now threatens civilised nations. In spite of the development of modern transport and commerce an intimate relation is seen to exist between natural resources and the size of population and standard of living a region can maintain. The density, distribution and movement of population must in general be governed by the amount, character and geographical location of resources and the occupations of the people.

ECOLOGICAL TREATMENT OF THE PROBLEM.—It is clear that the problem of population can be scientifically treated

(1) "The Theory of Population," *Economica*, March, 1928; also Wolfe; "The Population Problem since the World War," *Journal of Political Economy*, December, 1928.

only on the basis of particular areas, what geographers call "natural regions". Many of the cheap generalisations and over-bold maxims in the field of population literature are traceable to lack of a concrete regional outlook and obsession with the abstract postulates and tendencies of human behaviour bequeathed by the classical school of economics. It is noteworthy that Malthus's generalisation gave the cue to Darwin in his studies in evolution, and, indeed, the subsequent emphasis of struggle rather than sociability and co-operation led the science of life somewhat astray. The natural region concept serves as the corrective of many hypotheses. The conception of the web of life and of linkages, which maintain the conditions for a reciprocal common life of organisms in a particular natural region, which has supplemented the old idea of the struggle for existence in the new biology is, for example, considerably reinforced by the ecological outlook, and has proved of immense significance for the study of animal numbers. There seems to exist a balance of increase of numbers for all in nature. The numbers of animals of any given species are kept within bounds by a complicated chain of food relations; although, the check of the limitation of food supply is less important than the presence of predatory enemies and parasites in maintaining a suitable density of animal populations in wild nature. Such principles of balance as seem to operate throughout nature throw light on the condition of growth and of assuring optimum conditions in human population. For man, after he has reached a certain density, cannot with impunity exert his powers of aggression against the animal world, against the land and trees, his habitat; for it is on the natural balance of the entire regional complex that his security and prosperity largely depend.

ECOLOGICAL AREAS OF POPULATION.—A scientific approach to the problem of population then would be an ecological one. The study of human numbers should start with an examination of the relationship between man and natural factors, resources and possibilities, region by region. We have first to estimate the population capacity

of a region, as governed mainly by geography and geology. Each ecological area is endowed with a certain climate and rainfall, which remain the rock foundations of agricultural plenty or poverty. There is a reciprocal adjustment of agriculture, food and population. Thus intensive surveys of rather small ecological areas will indicate the limits of agriculture, food-supply and population capacity of the areas concerned. In the overcrowded regions of the world there is gradually established a close adjustment of crops, agricultural methods and practice to topography, soil and climate, so that each ecological area may serve to maintain the largest possible human community. It is in these regions that we best realise that the human community is determined not merely by physiography and climate, but also by the vegetable and animal communities, with which it constitutes the regional complex. Therefore, even in the most favoured regions, man's aggression against land, tree, and water, or lack of bio-economic co-operation, turns the balance of the region definitely against him, and in so doing alters the conditions of his optimum growth or depresses his standard of living.

TESTS FOR OVERPOPULATION.—The next task is to see whether and to what extent the optimum population with reference to a certain norm or standard of living, however it may be expressed, has been overstepped. There are certain agricultural and social consequences which accompany overpopulation, and these should be classified. Overpopulation is, however, a relative term. As the arts of agriculture and industry improve, a people which has passed the maximum density may continue to increase its numbers without lowering its standard of living or diminishing its total well-being. On the other hand, some countries, under present-day conditions of urban-industrial existence, exhibit a phenomenal reduction of birth rate. On account of rapid industrialisation and unchecked development of city life, the birth rate has been reduced by half within fifty years in some European countries. The cities increase in population, but the urban population has reduced its numbers of offspring, and shows

lowered vitality and vigour, while the villages which formerly comprised a prolific population also show sterility. Concurrently with a general reduction of mortality, the death-rate of the middle or effective and advanced ages has shown an increase, due not merely to excessive urbanisation, but also to the lack of leisure and healthy recreation, and to intemperance, in modern life. The productivity of the industrial nations has marvellously developed, but it has been unequally distributed among the different classes, and between cities and agricultural districts, for lack of right occupational and cultural balance. In the U.S.A., for instance, though the agricultural population has increased with general population expansion, the percentage to the total population has fallen from 60 per cent. in 1900 to 48 per cent. in 1920 and 25 per cent. in 1930. Since the war the total acreage of farmland has decreased and farm population is nearly stationary. On account of the drift from agricultural to urban and industrial life, the proportion of farmers is diminishing in most countries in Europe. Meanwhile the spread of free compulsory education, and the desire to maintain an artificial standard of comfort, intensified by economic pressure, have diminished the desire for offspring among all classes. The child-labour laws have also curtailed opportunities for rendering children remunerative to the family. For France with her depopulated provinces, for Germany and Italy with their huge mortality in the last war, the encouragement of births by suitable measures has been placed in the forefront of their national programmes. The peoples are now being re-educated to correct the present underpopulation, which by no means corresponds to the socially desirable standard of living. It is well known that among animals underpopulation is accompanied by the danger of the species being wiped out by exceptional disasters. Pearl found that the maximum density is not the optimum density for the population of fruitflies bred in the laboratory. Robertson observed that if there are too few infusoria in a culture they do not thrive.[2] Underpopulation is undesirable so far as the

(2) Elton: *Animal Ecology*, p. 116.

survival of certain protozoa and wild animals is concerned. For most human communities, overpopulation rather than underpopulation is the menace, and its "laws" have to be sought for and discovered.

ECOLOGIC CONTROL OF ANIMAL POPULATIONS.—The study of experimental bacterial population by Pearl, Oscar Bail and others has shown certain trends. The population student has to examine whether these trends hold good of human numbers in congested areas. As evolution has progressed, the number of offspring produced by the animal has decreased. Instead of an indefinite number of offspring left to shift for themselves in the struggle for life, as in the case of lower animals, we find among the higher ones a limitation of the number of offspring and parental effort to nurture and teach the young. The development of the parental impulse is one of the most important factors in maintaining progressive evolution. Among the highest groups of animals, "the evolutionary status of any particular type is directly proportional to the length of time during which parental care is exercised."[3]

Certain species of herbivores, in spite of small production of offspring, however, multiply enormously owing to favourable conditions of food-supply. The numbers of many of these fluctuate considerably and often rather regularly, being controlled by climate and food-supply, and also by parasites which produce periodic epidemics. The arrangement of eating and of being eaten, however, results in the numbers being effectively controlled in the majority of cases by predaceous enemies. The investigation of animal numbers by Elton, McKendrick, Forbes and others in these fields is of great significance. The territorial system among carnivores, apes, antelopes, bisons, elephants and certain birds, and the system of spacing ant-nests, bee-hives, and termitaries, also

(3) Dendy, *Biological Foundations of Society*, p 188, see also Mitchell: *The Childhood of Animals.*

act indirectly in checking numbers. The populations of social insects have been studied closely by Wheeler and Forel among others. In the insect societies which resemble human communities in all fundamental biological characteristics, Wheeler has shown that an elaborate division of labour and co-operation between the different members of the same species enable them to maintain a denser population on a given area. The development of special worker castes ensures the collection and distribution of food, economy in its use and success in the competition with other organisms in securing supplies. In prolific species, these latter functions are so exacting that a further caste, the soldiers, may be developed to take over the defence of the society as a whole or to perform other duties which cannot be adequately performed by the foraging and nursing workers.[4]

Sex determination and control of reproduction through feeding have also a direct bearing on the problems affecting their numbers. As Imms observes: "The reproductive instincts present profound difficulties in communal life: unlimited exercise of this faculty would result in a population speedily overreaching its food-supply and finally the disintegration of social life. The true social insects have overcome this difficulty because among them the full reproductive powers are confined to few individuals and aborted in the rest." This physiological atrophy or suppression is brought about through pronounced specialisation of structure and behaviour as well as control of the quality and quantity of food given to the insects in their larval stage. The insect colony depends, in fact, on an *elite* of fertile females. In the hive bee it is well known that after fertilisation of the queen is achieved the luckless males are eventually driven out of the hive. On the other hand, among termites both sexes participate in the life of the society. In this respect they more closely resemble the human species although the enormous somatic and gonadic development of the queens in the higher

(4) Wheeler: *The Social Insects*, p. 308.

species of termites clearly indicates the pre-eminence of the female sex.[5]

Periodic flight or swarming also serves to relieve congestion in the colony. Migration is one of the ordinary activities of animals. Such migrations are daily, seasonal or periodic. In some cases migration is on a large scale, as among lemmings, field rats and locusts, and results in relieving overpopulation in the old habitat and the establishment of a new colony in another region under more suitable conditions. Much in this manner man has himself migrated, either to remove himself from the centre of distribution in order to relieve pressure, or to reach some part of the circumference, and so extend the range of the species.[6] Thus the facts and conditions relating to the increase and control of numbers of animals throw a flood of light on the growth of human populations, especially in the crowded valleys of India and China, where these have multiplied almost without any voluntary checks. As among animals, it is the limit of subsistence, and not that of the standard of living, which here determines numbers.

PSYCHOLOGICAL VERSUS ECOLOGIC CHECKS.—Social-psychological factors checking an increase of population first emerge in the chain of instincts and habits connected with the nesting, breeding, and brood-care of animals and the division of forests and grass-lands among birds, isolated carnivores or herds of apes, gorillas, kangaroos, elephants and buffaloes. In human communities which have advanced beyond the primitive state, both the development of gregarious and parental impulses and the protection of mother and child in a stable family group remove the natural checks to population. The psychological factors now operate, and these integrate themselves into the standard-of-living limit, keeping the size of population at a suitable density. Such checks sometimes become weak, as the result of various causes, environmental or social,

(5) A. D. Imms' article on Social Insects in *Encyclopaedia Britannica*, 14th ed.
(6) Elton: *Animal Ecology*, p. 157; also *Animal Ecology and Evolution*.

and then the danger of multiplication of population and of over-running the food-supply becomes more serious than in lower grades of life.

REGION OF DENSEST POPULATIONS MAN'S DEPENDENCE ON ECOLOGIC LAWS.—Our inquiry has been undertaken in the Ganges Valley, which is the most densely peopled area on earth, having a population of about 125 millions, or nearly one-sixteenth of the world's population. In some portions the rural density represents the highest record of aggregation of man. This vast expanse of unenclosed cultivation teeming with human beings may be divided into distinct agricultural regions, characterised by special features in cropping, irrigation and farm practice, and unequal in their population capacities. Our ecological analysis has shown that the amount and seasonal distribution of rainfall and soil fertility govern not only agriculture and food-supply, but also health and density of population. We here discern that the population by natural increase has reached in some areas the limit of its resources, so as to render aridity and irrigation the factors determining the density and growth of population. Thus, in one of the most fertile and productive regions of the earth, man has brought upon himself the penalties of unregulated fecundity.

Having by multiplication reached the subsistence level in relation to soil, water-supply and crops, the population tends to be either stationary or restored automatically to the equilibrium density in the same manner as insects and animals. Neither psychological nor cultural factors, which in other regions and communities largely govern trends of population, seem operative in this region. Men here hardly differ from fruit-flies, which propagate in a bottle, or the herbivorous animals confined to a given territory, so far as the forces of natality and mortality in relation to density and food-supply are concerned. With the increase of population beyond a point of equilibrium density, mortality tends to increase, and sometimes the birth rate is permanently lowered, and the average expectation of life diminished. In no area of the world

can the ecological control of human population be so vividly illustrated by census, agricultural, and vital statistics, tabulated by natural regions: no area, again, can show so much stability and freedom from disturbance in the bio-economic adjustment; hence this locality is ideally suitable for the purposes of a social-ecological survey.

OVERPOPULATION PHENOMENA AND ECOLOGIC CHECKS.—A very large part of the Ganges Valley is, indeed, decidedly overpopulated, and there is serious mal-adjustment of human numbers to food-supply. Over much of this area there cannot be any relief from the pressure of population through intensification of agriculture and increase of irrigation, which have almost reached their limits. The population accordingly cannot improve its standard of living and, having reached a stage of saturation in some areas in 1901, is now showing absolute decrease. The mortality curve tends to follow the curve of food-supply and the natality curve, but in an inverse sense to both, and both natality and mortality are gradually declining. The tendency of mortality to be increasingly higher than natality, which has been found in the case of bacterial populations after the saturation point is reached, is clearly manifest in certain groups of years. Population either actually decreases, or its rate of increase is diminished. There is no congested area in the world, excepting certain parts of China, where population pressure is exerted over so long a period and for which census statistics are available for the search for functional laws of population trends. Professor Pearl's logistic curve seems to have been followed by several ecological areas in the Ganges Valley. It is limitation of space which affects the birth and death rate of fruit-flies when they reach a certain density. In the case of men, however, a limited area as such can have little influence, excepting, perhaps, under congested urban conditions. For, to men, square miles of area have their significance, as representing so many measures of wheat, rice or maize. Hence the changes brought about in natality and mortality are connected with the limitation of

food-supply, not of space. In the Ganges Valley neither social customs and traditions, nor social changes or events, nor again diseases like malaria, cholera and small-pox, appear to have had ultimate effect on population growth, and the population in some areas has come to decline without other catastrophe than the famine, which is always the ultimate check on numbers. But in practice other factors come into play before that condition is reached. Thus we find an increase in the death-rate and, sometimes, a decrease in the birth-rate, or generally a decrease of survival rate, automatically keeping the population in a given area at its equilibrium density, which is far from being the same as its optimum density.

CRITERION OF OPTIMUM DENSITY: DISTINCTION FROM EQUILIBRIUM DENSITY.—The distinction between the optimum and the equilibrium density is of prime importance in the theory of population. The optimum has been considered by various writers on the subject as associated directly with the standard of living, a concept, however, which eludes definition. Certain writers have attempted to adduce other criteria of the optimum, and there has been a good deal of confusion in this regard.[21] I have defined the optimum population in terms of the highest average expectation of life, a criterion which has been seen to apply to the phenomenon of growth of sub-human organisms. The mean duration of life among men is affected both by poverty and a luxurious mode of living, and the highest productivity is the result of the highest average longevity which, therefore, may be regarded as the norm from the economic as well as from the biological and moral standpoint. The average expectation of life is a tangible and measurable factor, and it shows a clear relationship with the size of populations, human or sub-human. Experimental populations seem to show a steady diminution of the mean duration of life when a certain density is overstepped, even though there is no per capita decrease of food consumption. With extremely high densities of population, the mean duration of life

(21) See *Proceedings of the World Population Conference*, 1927, pp. 72-108.

approaches an asymptote. Among animal populations we similarly find a decrease in fertility with density which maintains stable conditions. In the case of many of the small animals such as deer, antelopes, lemmings, rabbits and field rats we also find that other factors, such as the presence of their usual enemies, or the cycle of malignant epidemics, usually keep numbers down well below the point which would bring the population in sight of starvation. Besides the parasites the physico-chemical factors of the environment keep down numbers. As an organism increases in numbers, it necessarily spreads in both space and time. As it spreads it moves to points outside its optimum environment when its rate of multiplication immediately diminishes. Thus, as W. R. Thompson observes, "even under most favourable conditions, there cannot be a continuation and uninterrupted increase in numbers, but simply an oscillating movement, which is more likely to be feeble than extensive, because of the narrowly circumscribed optimum and restrictive adaptive powers of the majority of species".

Primitive societies, by adopting various customs such as infanticide, abortion or abstinence from sexual intercourse during periods of pregnancy and lactation, keep down population. This has been clearly shown by Carr-Saunders. An agricultural community, through the development of intensive farming and rotation of crops, can multiply much more than hunting and pastoral communities. Yet the danger of actual starvation or famine, acting as a check on human numbers, is real, because of the sudden catastrophic shrinkages of crops, especially in regions of uncertain and irregular rainfall. But even here, before famine actually reduces numbers, there is an indirect adjustment of density to food supply through the increase of mortality (as among the smaller mammals) or diminution of birth rate (as among fruit flies), or both. In this way the equilibrium density is maintained below a point at which actual starvation sweeps away human numbers. It is through the indirect trend of the survival-rate that the population finds its ecologic equilibrium. The

adjustment of numbers to stable conditions through the survival-rate is brought about through the operation not of undefined "forces of nature," as Pearl's law seems to suggest, but of a variety of definable and to some extent controllable factors. First, overpopulation, of course, implies some degree of limitation of food-supply, at least for the economically weak. Malnutrition, then, is an obvious cause of lowered vitality, which brings in its train disease and death. It causes sterility when certain elements of the diet are eliminated. It may also bring about increased fecundity due to loss of control over sexual life. On the other hand, during periods of stress the opportunities of a sexual life may be fewer, and this may also account for lower birth-rate. Overpopulation, again, implies congested housing conditions, at least for the poorer classes. This involves a loss of privacy, and consequently fewer opportunities for cohabitation. Congestion within the family dwelling or the village site causes insanitation, with its train of epidemic and fatal diseases. Lastly, an increase of competition and the wear and tear of the system diminishes the power of resistance, thereby paving the way to increased mortality. The equilibrium of population is accordingly brought about through a variety of causative factors, which mutually influence one another. The effect of any single factor may not be discerned in isolation, nor can it be quantitatively estimated with accuracy.

SOCIAL CONTROL OF POPULATION.—Biological, social and psychological factors coalesce to determine the survival-rate of a community and serve to maintain an equilibrium density. In this adjustment the agencies of social control are of prime importance. Infanticide, abortion, or castration among primitive races represent man's attempt to make the best out of existing limited food resources. Municipal housing and sanitation, state aid to agriculture and control of food-supply, and state subsidy to larger families, represent in modern civilisation the community's effort to combat the menace to a people that must live and multiply. The population problem becomes

biological when the agencies of social control are weak or absent, and the causes of population growth or decay are neither properly understood nor rationally considered. For a self-conscious community which believes that death and disease can be overcome, and which can set up adequate and adaptive agencies for the purpose, the population problem becomes one of economic, sanitary and social adjustment. For less advanced communities, the biologic processes run their course unchecked, as in the case of lower organisms, and the laws of natality and mortality seem immutable. It is sometimes urged that the defect of treating the population problem as a biological one is the neglect of human motives and aspirations. We do not find these much in operation in the natural region we have selected for population study; and, indeed, our corroboration of the fundamental trend of human numbers is a good augury for demography as a branch of biology studying the forces of natality and mortality in relation to natural regions. No doubt, with the spread of democracy and individualism, the social and economic emancipation of women, and the universal appreciation and demand for a worthy plan of living, it is the rational direction of the individual and the group rather than nature's forces or customs which will determine more and more the equilibrium of population. What nature now accomplishes, sometimes relentlessly, sometimes imperceptibly, will then be raised into a conscious social policy and individual creed. Man will then seek not an equilibrium but an optimum density. The standards by which he will determine the latter will be more his choice than the dictate of his region, and his ecological adjustment will be raised from an instinctive to an ethical plane. Accordingly he will aim at obtaining the optimum density that he desires with the least number of births, his economy of reproduction furnishing the basis of the total well-being of his species.

PRODUCTION AND REPRODUCTION.—The economy of reproduction is basal for every living organism. Professor Goldscheid observes: "A deep-seated connection exists

between the economics of production and those of reproduction. Production can only be rationalised if one undertakes to rationalise reproduction just as intensively and intelligently. Economics consists of economics of merchandise and of people. It is not until we consciously develop economics with reference to human beings and when we learn to put capital that lies in humanity to an economic use that we shall obtain at the same time the optimum density for a definite period, and according to the culture in question, so that economics of reproduction will thus be the basis of economics generally." The rationalisation of production consists, of course, in the improvement of the arts, which may economise labour and add to resources and the means of their utilisation for the diverse needs of the population. The improvement of the means of communication and transport and the loosening of communal bonds are bringing into prominence another mode of population adjustment, *viz.*, migration.

WORLD'S POPULATION PROBLEM.—The problem of population is thus inextricably bound up with the problem of finding out the right occupational balance; in India and China by rapid industrialisation—which, however, is limited in scope due to lack of adequate mineral resources—and of opening out outlets of emigration to appropriate regions where both stock and culture may easily establish themselves. With each new adjustment, both equilibrium and optimum population would vary, the density as well as the average duration of life increasing as economic mode and social organisation are perfected. Lastly, the density and standard of living of one country influence those of other countries. Labour and capital, methods of production, and standards of living migrate. An advanced agricultural community, which by its conservative agriculture maintains a dense population, may through the utilisation of mineral and hydro-electric resources attain higher productivity, and hence a new optimum balance and standard of living. On the other hand a hostile tariff policy or restriction of immigration, or, again, friction or

waste in production due to strikes, lock-outs and wars, upset the population equilibrium. There is more lack of equilibrium than reciprocal adjustment of productivity, density and standard of living in the world to-day. If we accept Knibbs's estimates, with a one per cent. annual increase the population of the world in 2000 would be 3,992,000,000 and in 2100 10,797,000,000. While the density of population varies greatly, possible expansion is limited. Only 5·1 per cent. of the total land surface of the globe is arable, and only twice that much more is comprised in pastures, scrubs, forests and marshes. Over-population is now a menace in most parts of the civilised world, and the time has come for a wise husbandry and fair equitable distribution of the world's resources, irrespective of race, colour or political considerations. The idea of the optimum population cannot be realised unless there is some sort of international control of the distribution of the world's surplus population. The world is advancing towards a new interdependence and co-operation of resources, both human and natural, of different regions which will not tolerate an exclusive policy, whether of exploitation of resources or exclusion of immigrants. Both in Asia and Africa modern trade and commerce have somewhat retarded the harmonious adjustment of the less advanced or primitive tribes and races to their environment: while modern sanitation has conserved human life among these with zeal and care. Ross points out that economic imperialism which casually summons into existence myriads of blacks and browns in order to make a profit of them, has been the greatest population-encourager humanity has ever known.[22] Promotive imperialism and Oriental exclusion are both emphasising the present maladjustment of population to resources in the world of to-day, where five-sixths of its population are crowded on only one-tenth of its land surface. Baker estimates that arable land, including both land in crops and that physically possible to use for crops, is approximately a billion and a half acres each in South-Eastern

(22) Ross: *Standing Room Only?* Ch. VII.

Asia, Europe and North America, the three principal population centres of the world. But South-Eastern Asia and adjacent lands contain about 900 million people, whereas Europe has only 500 million people, and North America less than 150 million people. Thus there is fully three times as much potentially arable land per person in North America as in Europe, and about 6 times as much per person as in South-Eastern Asia. But North America's population is increasing about 1·5 per cent. a year while South-Eastern Asia's as a whole is probably at present stationary. Since about 1870 there has been apparently no increase in the population of China, which stands at about 474 millions. China is now sustaining nearly four times as large a population as that of the United States on about half as large an area in crops.[23] India, with an area about half that of the United States, has a population almost three times as large. In the 16th century, the population stood roughly at 100 millions. In 1931 the population stood at 353 millions, increasing by 10·7 per cent. during the decade 1921-1931. India and China show similar rates of growth (1·2 or 1·5 per annum). Japan, with an area equal to one-twentieth of that of the United States, is able to support a population of over 65 millions, or over one-half of that of the United States. During the past 60 years population has doubled, and it is increasing by nearly a million every year. Baker observes: "Nowhere else is agriculture so intensive and so efficient in the utilisation of land. The possibilities of production are more closely approached probably in Japan than in any other country of the world." A proper appraisal of South-Asiatic standards of small-scale intensive farming, vegetable diet, and omission of animal raising, which have contributed to maintain nearly half the population of the world on a relatively small fraction of its surface, seems essential for an adequate understanding of the most economical use of the land.

(23) Baker· "Population, Food-supply and Agriculture," *The American Geographical Review*, July, 1928· "The Progress of Population," in *Problems of the Pacific*, pp. 318-338.

WAR NO SOLUTION.—An improvement in the standard of living, a scientific and humanitarian attitude towards life and birth-control, adopted by the advanced as well as the backward classes of each country,—all these must be accompanied by an equalisation of opportunities for expansion in order that the population problem may not become the Yellow or the White Peril and lead the white, black or brown populations into another great war that seems to be brewing in the region of the Pacific. Even if the expanding populations should engage in such a conflict, it would not solve but rather would accentuate the difficulty of the population problem.

CHAPTER III.

POPULATION AND THE USE AND MISUSE OF LAND.

Population of the World.—Social ecology studies the adaptation of human communities to living conditions. The cardinal subject of inquiry is the adjustment of population to resources. The population of the earth may now be estimated as, probably, 2,320 millions. It is divided into continental groups, according to an estimate of the League of Nations, as follows:—

	Year. 1900	1930 (In millions)	1932
Asia	859	992·5	1,113·1
Europe	400	505·1	549·7
Africa	141	142·4	144·3
North America	106	168·75	172·2
South America	38	82·75	87·3
Oceania	6	9·88	10·0
Total ..	1,550	1,901·38	2,076·6

There are two, and only two, areas on the surface of the earth, China and India, which deserve comparison with Europe in so far as they support a denser population by intensive agriculture. These three, excluding the thinly-settled regions of Western China, the table-land of the Deccan, and Northern Europe, do not comprise more than one-twentieth of the earth's land surface. Yet they embrace fully one half of its people.

Agriculture, Food and Population.—It has been estimated that 90 per cent. of the land area in Europe is productive; of this 40 per cent. is actually cultivated, 36 per cent. is under grass (meadow and pasture), 19 per cent. is under woods and forests, and 5 per cent. is classed as

marsh, heath, fallow, or put to other uses. In China, out of 1,000 million acres, 700 millions, or 70 per cent., are available for agriculture, the rest being locked up in the form of forest, pastures, forest preserves, pagodas and townships. Out of these, 180 to 200 million acres were cultivated in 1918, according to Chinese official data, or 25 to 30 per cent. In India 76 per cent. of the total land area is classed as productive. Of this 56 per cent. is under cultivation, 24 per cent. under grass, 18 per cent. forest, and 2 per cent. put to other uses. China and India together constitute nearly 36 per cent. of the world's population, and yet in these regions the proportion of cultivable land to total area is smaller than in Europe. In spite, however, of this disadvantage, the plains of China and India are much more heavily populated than the West-European area. The reasons are not far to seek. These regions lie within the monsoon zone, where the simultaneous occurrence of abundant rainfall and great heat has proved especially favourable to vegetative growth. It is noteworthy that the largest numbers of cereals and plants now available for human use have been domesticated in these regions. The world's heaviest human concentration has been reached in the deltaic tracts in India and China, where both inundation and rainfall have contributed to phenomenal intensification of agriculture. In a warm climate, again, the standard of human needs is low, providing ideal conditions for growth of numbers. Already the rural density of the Gangetic plain at some places is very much higher than the densest portions of rural Europe, being over 3,000 per square mile. The export of food grains from this granary bespeaks potentiality of further increase in density without disturbing the standard of living of the population. The greater the density in rural areas the closer and more stable is the adjustment of the arts of living to natural conditions. It is for this reason that social ecology can find most important material in these densely-populated rural areas, where men can maintain themselves only by closest adaptation of crops and farm practice to soil and climate. In the crowded regions of the industrial West the conditions

of living equilibrium are maintained by the importation of food from abroad, and the export of manufactured goods which buy that food. Among the mass of settled inhabitants in India and China, on the other hand, the ecological organisation is based on the local distribution of crops, which governs both the size and character of the human community. Population seeks food-areas along lines of least resistance. It is the topographical features which govern the main lines of settlement. As in plant communities, we have in human communities stages of ecesis or migration. The pioneer settlers represent conditions of mobility and instability, but gradually a stable living equilibrium is reached. Man selects some plants or animals from among the stock of the region; and these, instead of exterminating, he tolerates and nourishes. At first he burns forests and grass-lands, but gradually learns by trial and error to maintain pasture grounds and to devise elaborate rules as regards grazing and the use of meadows. He thus gradually becomes attached to the land in the full sense of the word, and no longer behaves as a cancerous tissue bringing about a parasitic degeneration in his immediate surroundings. Ceasing to be merely predatory or exploitative, man establishes interrelations with the plants and animals of the region and links lives together in reciprocal service and adaptation. This ecological process has continued from the very dawn of organic life, and the balance between the organic and the inorganic world, achieved as its result, becomes of the highest importance in regions where the stationary peoples have to cajole Mother Earth for their sustenance.

AGRICULTURAL BALANCE IN AN OLD REGION.—As a basic principle, natural regions for intensive studies in social ecology are those wherein the environment operating for many generations has developed a stable bio-economic balance. An ancient, historic region, like the Ganges plain, resembles from an ecological standpoint an old forest area far from the haunts of man, where time has

allowed species and varieties of plant communities fully to adjust themselves to their habitat, and no disturbing factors operate to bring about a new cycle in plant succession. The Ganges Valley may itself be divided into several natural areas where man's cultivation, interests, and habits respond as plant communities to such ecological factors as annual range of temperature, rainfall or nature of the alluvium. No better instance of such adaptation can be adduced than the fact that there are altogether several thousand varieties of rice in the Plain, adjusted to conditions of soil, climate and the level of flood-water. Many of these varieties are so closely adapted to their respective districts that if interchanged one may not grow at all on the fields where another has thrived for centuries. No doubt great progress has been achieved in the country as a whole in plant-breeding; but it has been found that exotic varieties have less chance of success than races isolated from the crops already adapted to the soils. Furthermore, agricultural research indicates that there is a limit to the improvement of crops by plant-breeding, and that limit depends upon the indigenous farming practice. A heavier-yielding type must make greater demands on the soil, and its introduction should be accompanied by a change in the local system of agriculture, which will enable the soil to regain its fertility. Unless this is done the yield of the new type must inevitably deteriorate until a new balance is struck between crop production and the regeneration of soil fertility. The balance will probably come somewhere about the level of the old yield of the local crop.[1] Similarly, the indigenous agricultural practice differs strikingly from region to region, even with reference to the same crops. The stages of agriculture, again, are also dominated by the same factors which determine ecologic succession in the vegetative cycle. In the Ganges Valley man is also remarkably free from migratory habits. Here progress, including agritural progress, can best illustrate the complex interwoven growth of biological mutuality, which continuously evolves

(1) Shaw's evidence, *Report of the Royal Commission on Agriculture in India*, Vol. I, part II.

reciprocal service to the uplift of the entire biotic community.

The Ganges plain, therefore, is an appropriate field for an understanding of social-ecological principles. Population moving along the course of the river has now been stabilised for centuries in relation to climate and earth factors. There is a likeness in the occupations, habits and manners of the people, almost as unalterable as rainfall and soil. By centuries of adaptation so close a correspondence between the biotic and inorganic factors is established that the fluctuations which the land form, the river system, or the distribution of rainfall naturally are subjected to, or the artificial changes which biotic interference inevitably brings about in the ecological complex lead to enormous reactions in human life. The study of the human community in its relations to the sun, earth, and water yields, therefore, for this natural region, important conclusions as regards both social and environmental control.

FARMING AND FIXATION OF SOCIAL AND RACIAL TYPE.—Wherever man has multiplied in large numbers, he must lead a more settled existence, and hence is far more dependent on the animal and the vegetable covering of the earth than elsewhere. His comparative stability allows the climate directly, as well as indirectly through diet and occupations, to exercise on him its full effects. Thus his physical and mental characteristics here bear the impress of the region more than where he is nomadic or at least less stable. A very dense population can be maintained only by agriculture. Agriculture, therefore, tends to the fixation of a social type. But not merely are man's physical and mental characteristics, his occupations, habits and interests fixed in this manner. There is a similar adjustment of plants and animals to human factors. The selection and cultivation of plants and domestication of animals directly depend on man's stage of economic development, his economic traditions and experiences. On the one hand, climate, soil, and animal and vegetable

resources govern materially the economic method and the social life of man; on the other hand, food and type of labour evolve the racial type which can best utilise the resources of the region.

REGIONAL CHANGE AND BIOTIC INTERFERENCES.—Thus, the region has to be conceived in the light of the interplay between animate and inanimate nature. It is growing, plastic, fluent, its chief characteristic being to reach an equilibrium, though a shifting one. There are changes in the inanimate environment,—changes, for instance, of climate which are cyclical or occasional, slow or catastrophic, with far-reaching effects on plants, animals, and men. There are also slow and inevitable changes of soil and topography of the land, associated with the natural effects of rainfall or the natural history of the river system. Such changes govern the succession of both plant and animal communities. Then there are changes in both inorganic and organic nature brought about by biotic interference. Thompson observes: "Wild nature is in a state of moving equilibrium like that of a top. Usually however the oscillation in the old established arrangements of eating and being eaten are within narrow limits, unless man interferes, or unless some big change occurs in climate and other physical conditions. When there is a succession of hard winters (and droughts) or of fine summers, the ripples may become waves."[2] But the hand of man which is often heavier indirectly than directly, sets in motion mightier waves. Man clears forests and prepares fields for cultivation, he grazes animals on the hillsides and uses trees for fuel, for thatching, for tanning and other industrial purposes. All this leads to a change in the type of vegetation. Man not only reclaims the mountain slopes, but he also redeems the marshes and swamps. He digs wells and canals, builds roads and railways, and seeks to efface the effects of natural features or the vagaries of climate on his life and manners. He deliberately destroys many wild animals and tolerates and domesticates others.

(2) Thompson: *Biology of Birds*, pp. 492, 411.

He also introduces new animals from other countries. But he more often alters the equilibrium of nature indirectly rather than directly. Thus the destruction of the carnivore and the increase of cultivated land mean an increase of the rodent. The multiplication of rabbits and rats, voles and insect pests involves new dangers to man, and the destruction of birds, which keep a check on creatures that injure useful animals and plants, also generates new ripples in the pool of organic being.

BALANCE OF MAN'S CO-OPERATION AND EXPLOITATION.—Man's social and cultural development, as well as increase of numbers, brings about changes in economic methods and indirectly transforms the region through the nature and kind of vegetable and animal resources he prefers. This amounts to an increasing process of inter-linking of the living and the non-living world. Man and the region are not two separate factors. They mutually influence each other, and form a natural balance, each part of which can be understood only in terms of the other. Social progress lies in the discovery of the right balance of man's co-operation and exploitation of the ecological forces of his region. This alone can furnish him with the best material background in inorganic and organic nature, including his own permanent works and products, which may serve as the stable physical basis of his optimum efficiency and living conditions.

Under the influence of the human community, itself changing its technique and arts of production in course of time, the region undergoes development or deformation, perhaps reaching a bio-economic climax of development, unless rejuvenation sets in through the introduction of new cultural elements.[8]

By a diagrammatical arrangement we may illustrate the moving equilibrium of the region in both its developmental and its retrogressive aspects.

(8) Compare Sauer: *The Morphology of Landscape.*

REGIONAL MOVEMENT.

Plains-Region ↑ Interaction ↓ Man	Development ↑	Soil Management: Manuring Leguminous cropping Control of Water-Supply: Use of rivers (Canals) Use of subsoil water (Wells) Flush irrigation Agriculture: Intensive farming Utilisation of cultivable wastes Animal husbandry and dairying Management of pastures Afforestation Building of dams and plantations of defensive vegetation to prevent erosion River training and regulation	Increase of population density Excess of birth-rate over-death rate.
	↓ Deformation	Soil Exhaustion Destruction of forest and vegetable cover Desiccation Soil-erosion Unsound and unsuitable irrigation Silting up and meandering of rivers Lack of natural drainage Growth of jungle on village sites, of rank weeds in swamps, and water-hyacinths and algæ in streams Insanitation Deterioration of breed and power of cattle Famine and disease	Decrease of population density. Excess of death-rate over-birth rate.

CONTRASTED EFFECTS OF ANCIENT AND MODERN AGRICULTURE.—Where population shows no progress in the arts of production but multiplies beyond the resources of the region, the arts of living are at first as closely adjusted to natural conditions as possible. But soon the ecologic balance between the natural and the vegetable and animal environment (including men) is upset, bringing about both the deterioration of the region and of human society.

Such disturbance of the balance of the region, which affects man's living conditions, is often clearly discernible. Sometimes, however, it is difficult to comprehend the changes which man sets in motion, breaking the rhythm of nature in unsuspected ways. One instance may be adduced. Economic entomologists now divide the world into two areas for a survey of the problems which confront them, that of ancient and that of modern agricultural practice. The areas of ancient practice—those following the small plot system—are free from major insect pests, excepting where the plantation system of cultivation has been introduced. Modern agricultural methods mass insects' food media together, tend to remove competition from certain insect types, and enable them to increase in numbers and so acquire the status of pests. Further, geographical barriers to distribution are removed by the agency of man under civilisation, and the spread of insects from endemic areas is thereby facilitated.[4] Thus the development of commercial agriculture, which often exhausts the soil, bearing as it does no relation to its requirements, is responsible for the growth and spread of destructive insect pests which play havoc with crops, and sometimes with men and domesticated stocks.

Such disturbance of the ecologic balance early manifests itself in man's one-sided exploitation of the land, and of natural, and vegetable resources, without that mutual service which alone can keep alive the never-ending cycle of nature's processes. Man commits crime against soil, tree, and water, and nature's vengeance follows quickly. In a river valley, the different sections or levels—forest pasture and tilled land—have reached a bio-economic equilibrium which man disturbs as his increasing numbers demand food, fuel, and other materials for their living, which the mature plain cannot adequately provide.

AGRICULTURAL DECLINE.—The story of agricultural decline in old countries is connected with denudation of

(4) *Nature*, August 31, 1929, p. 328.

forests on hill slopes, or, again, the exhaustion of the soil by surface tillage, inadequate manuring and the introduction of the one-crop system by manufacturing and commercial interests. It is true that geological changes or climatic modifications have contributed to the decay of societies, especially in marginal regions. Such natural events are said to have caused the fall of ancient civilisations in Central Asia, Chinese Turkestan, Cambodia, Central America and Bolivia. But more often the violation of the natural rhythm between the integral sections of the region, or the sacrifice of one section to another, which are man's outrages, have brought into operation forces, which have deteriorated and even completely desolated the earth. In Mesopotamia the pasture land overwhelmed the tilled land, when the nomadic races and flocks trampled down agriculture, and destroyed the elaborate irrigation system. In England in the 14th century the demand from the Continent for English wool, and still more in the 16th century, the development of wool manufacture at home, resulted in the conversion of fields into sheep pastures and the enclosure of much common land, upsetting the normal balance of occupations. In ancient Spain the tilled land climbed the heights, replacing the forests, when eventually the lapse of tillage, the death of olives, etc., and the falling of terrace walls gave denudation free play. In the Ganges Valley we are witnessing to-day the gradual ascent of cultivation to the mountains, the transformation of river banks into bare and inhospitable ravines, and almost complete conversion of pastures into tilled lands. Deterioration due to the maltreatment of the forest country similarly is spreading over the Punjab Siwaliks, where mile after mile is cut up, observes Baden Powell, with the broad belts of sand, not only useless, but spreading the desolation farther and farther with every hot wind and every flood. The mischief is not local, limited to the damage on the hill slopes, for the forest cover in the hills controls the flow in the rivers and the welfare of the agriculturists in the down-river areas, hundreds of miles away. Swamps and marshes have their use in rural economy. When cultivation extends to the

brink of marshes, and these are reclaimed for the plough, the rivers deprived of the storage basins, lose their vitality, and the water-level also tends to sink, making irrigation and agriculture more and more difficult. The destruction of trees in the level plains also has cumulative evil effects, tending to decrease the humidity of the air and the equality of temperature, while the grazing of countless herds of cattle, sheep and goats on the river banks destroys the jungle cover and makes soil erosion a serious menace to cultivation. The annual loss of organic matter from crop and pasture land, due to erosion has been estimated in the United States at an average of 322 million tons a year, and losses of 50 to 60 tons of soil per acre per annum have been verified for certain types of soil and cultivation.[5] The reduction of open grazing lands and inability to devote any but a mere fraction of the holding to fodder crops, are causes of impoverishment of cattle and reduction of their numbers. Anaemic cattle, anaemic crops, and anaemic people are inter-related with one another. In the Bengal delta the increase of population has led to the building of embankments, roads and railways, upsetting the ancient natural overflow irrigation and drainage of the country. Thus there is not only decline of agriculture in areas, deprived of the fertilising silt, and yet exploited for centuries by the heavy pressure of population, but also malaria becomes rampant and carries off large numbers.

A comprehension of the complex web of life which shows the systems of animate and inanimate nature inextricably interwoven by reciprocal action and interaction may perhaps lessen man's pride. For social progress would be seen to depend more and more not merely on co-operation between fellow-men, but also on the maintenance of the conditions for the reciprocal common life of nature and human society.

UNITY OF ORGANISM AND ENVIRONMENT.—There are at least two far-reaching sociological implications of the view of regional inter-relations here presented. The

(5) Gorril: *The Use and Misuse of Land.*

living organism belongs to its region just as much as its parts belong to one another. Our environment is bone of our bone and flesh of our flesh. The influence of the environment on the organism, and of the organism on the environment, expresses the maintenance of specific *normal* structure and activity. From a physical standpoint, we speak of the balance of income and expenditure of material and energy; from a biological standpoint we speak of the unity of life, the life extending indefinitely beyond the confines of the body. Life is thus an actively maintained whole without spatial boundaries. Both the structure and the life activities of the organism must be manifestations of this organic unity, so that they fit each other in the manner found to be actually the case. Life has many forms; but for one organism the life of another is simply part of its biological environment, and consequently included in the unity of its life.[6] Plant, animal and human communities are systems of correlated working parts in the environment, the relations of some being independent and of others reciprocal; they are physiologically different in different regions, which they alter in their turn, in a continuous process. The boundary lines vanish and new points of contact emerge between the realms of the living and the non-living. From another direction do we comprehend the unity of physiological mechanism in all life, that the physiological is related to the physico-chemical and there is no abrupt break but a continuous march of law.[7] Secondly, man's kinship with the lowest of organisms suggests a new orientation in ethics. The reciprocal service and adaptation of the different parts of inanimate and animate nature, the realisation in the region of an underlying unity amidst a bewildering diversity, call for a wider pantheistic morality, envisaged under the aspect of conformity with the general and continuous law of Nature, which applies to society as well as to the larger environment of the universe. From the sociological standpoint, the fundamental notion is the balance of

(6) J. S. Haldane: *The Sciences and Philosophy*, Chapters XIII and XX.
(7) Compare Sir J. C. Bose's important discoveries

social forms and institutions in the setting of the environment, which includes both inanimate and animate nature. Any change in an external factor of the environment induces a series of changes in man's institutions. There is, again, a second series of inter-relations between the human individuals and the institutions of which they form parts. For man, the legacy of institutions and traditions is simply part of his life and activity, and is comprised in the unity of the social process. A change in the institutions alters the character of the individual, and *vice-versa*. Social life, therefore, represents a triadic balance of the individual, the institutions and the region.

CHAPTER IV.

CONCENTRATION OF POPULATION.

STUDY OF INDIA'S GREAT PLAIN.—The physical characteristics of a region leave an indelible stamp on the men who live in it, and have adapted themselves thereto. Perhaps nowhere in the world are the natural regions and boundaries so sharply differentiated as in India. Nowhere is the comprehension and study of the regions so fraught with social implications as here. Nowhere again is man's interference with the natural features so subtly interlocked with his hopes, his anxieties and his vicissitudes.

The most important of the natural regions of India is the Indo-Gangetic plain. This is the largest alluvial plain in the world, with a breadth of 100 to 300 miles, and an area of about 500,000 square miles. It is one of the world's richest stores of agricultural wealth and earliest seats of civilisation, and is the most densely populated region in the world. This vast plain is cut off from the peninsula by an upland of moderate elevation, which turns a steep and forested face towards it. It is, however, connected by narrow but accessible passes with Central and Western Asia, whose steppes have bred the world's most virile and nomadic races, famous for their migrations and conquests. The equator-ward drive of peoples of temperate and sub-temperate regions is an old and familiar event in history. The Indo-Gangetic plain extends equator-ward from the region, which has been the constant scene of the shifting and migrations of the more nomadic and militant races of the continent. It has thus received constant accessions of population, and to-day is the scene of one of the world's highest records of aggregated humanity.

The Gangetic plain may be pictured as a series of large belts of country laid out flat like a section of soil strata, exhibiting the upper and more fertile silt deposit towards the east. Almost everything enters the region at

the north-west boundary and runs through it south-eastward. Natural regions, rivers and drainage are imitated in this respect by roads, railways and canals, and the distribution of population follows the same trend.

The teeming millions in the villages can only be supported by phenomenal agricultural productivity. This has been possible as a result of various climatic and geographical factors.

FACTORS OF PHENOMENAL FERTILITY.—In the first place, the enormous mountain ranges in the north of India and the elevated land masses in the north-west and north-east have tempered the continental climate in the Indo-Gangetic plain. The Himalayas have caused this region to be warmer than Chinese districts in the same latitude. Secondly, the glacier-clad mountain ranges in the north, by robbing the monsoons of their moisture, have made the Indo-Gangetic plain a vast, liberally watered garden, and the regions in Central Asia arid wastes. Thirdly, the "washings" from both sides of the Himalayan range are brought by the drainage system into India. The Indus and Brahmaputra rise close together on the Tibetan side, while the great rivers on the Indian side flow over or through the Punjab, United Provinces, Bihar and Bengal. There is a great alluvial plain, of which one branch is on the eastern slopes from the Punjab to the Bay of Bengal, and the other descends westward to the Arabian Sea. These may be termed the Indus branch and the Ganges branch respectively. There is no reason to doubt that the upper strata, at any rate, of these great alluvial plains have been formed by silt deposit carried by the drainage of the Himalayan range. It is the silt deposit which accounts for the enormous agricultural wealth of the Indo-Gangetic plain.

Fourthly, both the Ganges and the Indus river systems have found in the Himalayas, which are covered with perennial snow, an unfailing reservoir, making it possible for more than a fifth of the cultivated land of India to be irrigated by means of canals. The agricultural

prosperity of the plains depends not only on the perennial flow of these mighty rivers, which have never dried up, and which, unlike the rivers of China, have never departed materially from their main channels, but also on the development of canals and the introduction of perennial irrigation.

Fifthly, the alluvium consists of a long and relatively narrow plain sloping from north and west. The uniform surface is broken by the valleys, which have been carved out by the rivers since the period when geological changes brought the surface of main alluvium about the level of flowing water. Geologists tell us that the alluvium forming the Gangetic plain is of fresh-water origin, and that it extends to great depths far below the present sea-level. These deposits have not yet been compacted into rock, and lie nearly horizontally, since there has been no considerable geological disturbance of the strata since their deposition. The depth of the alluvium is known to exceed a thousand feet in the central portions, and throughout this depth its composition is remarkably uniform, beds of clay and sand succeeding one another with little variation. In a formation of this kind, there is naturally a fairly uniform water-table—that is to say, wherever a hole is dug to a certain depth, water will begin to percolate into it. The depth of percolation level is determined mainly by the distance from the river valleys to which reference has just been made; and, though it varies from season to season with the amount of rainfall, it maintains its relative position with substantial regularity. This has led to an easy and cheap system of irrigation by means of percolation wells, millions of which are at work throughout the Indo-Gangetic alluvial plain. Mere soil fertility in the face of a deficient and precarious rainfall would not have accounted for the great concentration of population. Both in the Punjab and the United Provinces most of the winter crops require irrigation for their success, while in dry seasons well-irrigation becomes an absolute necessity for the maintenance of people on the land. Alluvial wells are easy and cheap to work and,

though these have their limitations, they have contributed not a little to protect a large and concentrated population against drought. The Jumna-Ganges Doab enjoys exceptionally good canal-irrigation. In the United Provinces well-irrigation vies with and in the eastern districts outstrips canal-irrigation. In the eastern districts tanks, *tals,* and ponds are very numerous, though well-irrigation is also considerable. Moreover, these districts are so situated that they escape the violence of the monsoon rainfall, which causes occasional havoc further west.

In the Gangetic plain both rainfall and fertility increase towards the delta lands. Thus the population increases in density south-eastward towards the Bay of Bengal.

RAINFALL, AGRICULTURE AND POPULATION.—The well-watered delta lands of the Ganges and the Brahmaputra support in places a population of over 2,000 people to the square mile. On the other hand, in the south-western Punjab the density is as low as 100-150 per square mile. In the western part of the Rajputana Agency there are only 38 persons to the square mile. This difference in the density of population is the result chiefly of a difference of rainfall. Not merely is the rainfall uneven in different parts of India, but its variations also are so critical that the cost of agriculture in certain parts is serious. When the rains fail altogether, or are unevenly distributed in a region of high rural density, the effects are catastrophic. In the Punjab the irrigated area lies in a region where the normal rainfall is from 7 to 25 inches; in the United Provinces it lies in the tract where the normal rainfall is from 15 to 30 inches. Without artificial irrigation the agriculture of this tract would have been too precarious. Roughly speaking, the northern famine region of India is covered by a triangle joining Ferozepur, Gujarat and Champaran.

It is significant that the climate towards the eastern limit is changing distinctly for the worse. In the district of Champaran Mr. Stevenson Moore, in comparing the

maximum and minimum temperatures of the years 1874 and 1898, observes that for every month the maximum temperatures of 1898 are higher than those of 1874, while the minima are lower. In recent years also the range of variation has been maintained.

YEAR	MAXIMUM.	MINIMUM.
1903	107	39
1904	103	39
1905	102	32
1906	105	39
1907	105	33
1908	107	36
1909	108	35
1910	103	44
1911	103	43

The maximum for 1874 was 94, and the minimum 49. The maximum for 1898 was 105 and the minimum 40. Observations have been discontinued for Motihari since, 1912.

Over the whole of Northern India, the fluctuation of the annual rainfall is clearly reflected in the vicissitudes of the peasant's life. A very large part of the densely populated Gangetic plain lies at the meeting of the two chief rain currents, and so has been liable to irregularity of rainfall as well as scarcity from times immemorial. These two currents of sea-winds, which may be called for convenience the Bombay and the Bengal currents, curve inwards towards India. Thus, to use figurative language, the rain-giving God, Indra, embraces maiden India with his two arms, clasping her almost from opposite directions. It is upon his will and caprice that agriculture in India depends, for he may give rain in opportune agricultural seasons, or may cause disastrous floods or still more disastrous famines.

MONSOON RAINFALLS OF AFRICA AND ASIA.—The monsoonal character of the rainfall of India has long been recognised. India is a tropical peninsula attached to the huge Asiatic land-mass in the middle latitudes and projecting into the warm Indian Ocean. The monsoon is due to the extreme seasonal heating and cooling of the Asiatic land-mass. Now the rainfall of India varies

inversely as the atmospheric pressure, as it does elsewhere in the Africo-Asiatic summer infrabar, or low-pressure area.

Since the rains of the Sudan and Abyssinia are due to the same cause, there is considerable similarity between the rainfall there and the rains of the south-west monsoon of India. Years of famine or excess rain in India usually coincide with low or high Nile floods (and hence with rainfall variation in the Sudan), since variations in atmospheric pressure (the cause of variation in the rains) are widespread in occurrence.

The end of the Asiatic low-pressure area lies shortly west of the Nile basin; while another "low" of almost equal size lies over the western Sahara between the Asiatic "low" and the Azores hyperbar (high-pressure area). The two, however, form a low trough from Senegal to China, one centre being north-west of Lake Tchad and the other over the Thar desert of India.

During certain years this low-pressure area fails to develop strongly, and these years coincide with the years of deficient rainfall in Sudan, the Abyssinian plateau, and Northern India. Such variations in pressure are simultaneous over wide areas, including the Sahara, India, Arabia, Persia, etc. These variations apparently depend upon a relation (at present little understood) between atmospheric pressure and solar phenomena. I have shown elsewhere that there is a fairly close agreement between drought and sunspot occurrence in India. In some cases the relationship is immediate; in others there is observable a lag of one or two years in the relation of sunspot activity and rainfall.

It is a matter of speculation whether the monsoon current has undergone any swing in its direction within historical times. There is no doubt that Central Asia has been drying up within the last thousand years.

Perhaps the monsoon formerly visited Arabia and Persia. How could we otherwise explain the vestiges of

numerous tanks, long since dry, for storage of rainfall in south-eastern Persia, nor a rainless region? In the highway from India to China remains are found here and there among the sands of a forgotten civilisation which reached a high development in arts, crafts and agriculture. Communities formerly flourished in Balkh, Baluchistan, Chinese Tartary and Turkestan, but these were parched out of existence long ago. The cause may be a progressive diminution in rainfall, or the desertion by the monsoon current of hill ranges which formerly fed the trans-Himalayan rivers; or the desiccation may be due partially to river capture resulting from the peculiar configuration of the tract. In 300 B.C. the Punjab, as described by the Greek historians of Alexander's campaign, received a more copious rainfall than it does now. Forests of timber trees appear to have existed where now there is only camel-thorn. On its return from India the Greek army marched along the arid Mekran coast west of Karachi. There was terrible suffering, but such an enterprise would be altogether impossible at the present time.[1]

EVIDENCE OF CHANGES OF CLIMATE.—There is some reason to believe that within the last few centuries aridity has been increasing in Northern India. It is true that Sir Gilbert Walker has produced evidence to show that there has been no radical change in rainfall since 1841, and to lead to the inference, based on the records of Nile floods caused by the rainfall in Abyssinia, that there has been no radical change since 1733.[2] More recent data, however, point to a different conclusion. In West Africa a scientific investigation has recently proved emphatically that desiccation is in progress; that it has been observed for sixty years, and that it has been greatly aggravated in the last 20 years (that is, the first decades of the 20th century). Of the causes, while granting other contributory factors, the experts ascribe first place to progressive diminution in rainfall, since there is a close similarity

(1) Fuller: *Studies of Indian Life and Sentiment*, p. 9.

(2) Gilbert T. Walker: "On the Meteorological evidence for supposed changes of Climate in India," *Mem. Ind. Mete. Dept*, Vol. XXI, Part I, 1900.

between the Indian and the West African rainfall, the presumption is that there is similar advance of aridity in the Indian marginal zone. As a matter of fact, it is in the marginal zone of the Indian infrabar that in the 19th century the Hakra river system entirely disappeared in the sands, wells shrank and water-holes filled up with sand. The Indian desert protruded a dry tongue to the north-east, and there is to-day a riverless gap extending to the hills below Simla, where an interval of only eighty miles separates the Sutlej and Jumna. Part of this riverless region, that lies north of a line drawn from Delhi to Multan, was once far better watered than it is now, where, but for artificial irrigation, it would be at least semi-desert. Some of the most ancient cities of India are situated in it. Some of its districts in early Muhammadan times produced a very much larger revenue than they did at subsequent periods. We learn from Muhammadan chronicles of movements of large armies about this region that would now be impossible if the conditions of those days as to supply and transport still prevailed. There was then a direct route between Delhi and Multan, passing through large and prosperous towns standing in a productive and well-watered country, towns that have dwindled in importance and would have perished but for modern canal-irrigation. The fact that chroniclers speak of the "rainy" season at places where now the annual rainfall is from five to ten inches only indicates that there has been some change of climate within the last few centuries[3] Artificial irrigation has checked the advance of the desert towards the north, but the Indian desert tends gradually to extend towards the east. South of the Jumna tract the water-level is steadily going down, pastures are being depleted, and certain crops are no longer grown. We have evidences of a diminution of rainfall from districts such as Muttra, where agricultural deterioration has been a matter of serious concern. In Sadabad *tahsil* in the Muttra District the well-water level has gone down from 40 to 45 feet to

(3) Arden Wood: "Rivers and Man in the Indus-Ganges Alluvial Plain," *The Scottish Geographical Magazine*, January, 1924.

75 to 100 feet within the last fifty years.[4] In parts of Agra, Muttra, Etawah and Jalaun districts, desert conditions are becoming more and more evident. The westerly winds, which are so detrimental to agriculture in the United Provinces, and which traverse the entire Gangetic plain in summer, are becoming hotter and drier. In the district of Etawah the desert is increasing at the estimated rate of 250 acres per annum. The vegetation also shows a change towards xerophytic types. How far the increase of aridity is due to a smaller rainfall within the last few decades, or to the destruction of the vegetative cover, or to river capture in this tract, remains uncertain. There cannot be any doubt, however, that without a more vigorous and forward policy of afforestation, as well as canal and well irrigation, agriculture in the south-western parts of the United Provinces will decline, and years of drought and scarcity will become more frequent.

WAR OF THE WINDS IN INDIA.—There is another reason why the rainfall is more uncertain in western than in eastern India. The Bombay branch of the monsoon, though much stronger than the Bengal current, has to overcome the obstacle presented by the Western Ghats, about 2000 feet high, and suffers a grievous loss of humidity. Thus its penetrating strength is reduced. On the other hand, in Bengal the delta slopes gradually towards the sea, so that the sea-wind sweeps inland without obstruction. This easterly current, which blows up the Gangetic plain, carries rainfall abundantly to Assam, Bengal, Bihar and Orissa, and in minor degree to other parts of Northern India. In the Punjab during the summer monsoon easterly winds predominate, and these are partly drawn from the current blowing up the Gangetic plain. But the westerly branch of the monsoon from the coasts of Sind, Cutch and Gujarat blows across Rajputana as a south-west wind, and in part coalesces with the former in the Northern Punjab, and at intervals the easterly wind gives way to a dry wind from the opposite quarter. This takes place during breaks in the rains; and, in seasons of

(4) Wells in the town of Bikaner to the south in Rajputana are 300 ft. deep.

drought, west and north-west winds hold possession of North-Western India for weeks together, penetrating eastwards across Central India, and down the Gangetic plain, even to Bengal and southwards to the Deccan and Hyderabad.[5] Such is the case in years of drought and famine.

The central part of the Gangetic plain is thus the battle ground of two titanic forces. One is beneficial which takes its origin in the Bay of Bengal and the Indian Ocean; the other is harmful, which arises from Western India and the Baluchistan table-land. The easterly wind is a moisture-bearing wind. This moisture is drawn not merely from the ocean, but also from the forests of Assam and the coastal plain of Bengal and Orissa. Recent studies of the relation of forests and waters in America have shown that precipitation of the eastern half of the United States is intimately connected with the prevailing south winds, that evaporation from land contributes more to the precipitation over land than evaporation from the ocean, and that forests evaporate more water than any other vegetation, or than free water surface.[6] There cannot be any doubt that the forests in the Assam and Chittagong hill tracts, as also on the coast lines in Bihar and Orissa, contribute more to the precipitation over land than evaporation from the Bay of Bengal.

FOREST AND WATER.—Numerous experiments in Europe in the level and slightly hilly forest regions have also proved that the forest, on account of its excessive transpiration, consumes more moisture, all other conditions being equal, than a similar area either entirely bare or covered with some herbaceous vegetation. The water consumed by forests is nearly equal to the total annual precipitation. In cold and humid regions it is somewhat below the amount, and in warm and dry regions it is above it. The ground-water table under forests was found invariably to be lower than in the adjoining open fields.

(5) Blanford: *Climates and Weather of India.*

(6) "Forests and Water in the Light of Scientific Investigation" by Raphael Zon, Appendix V of *The Final Report of the National Waterways Commission.*

The enormous amount of moisture given off into the air by the forest, which may be compared to clouds of exhaust steam thrown into the atmosphere, must play an important part in the economy of nature and deservedly earn for the forests the name of the "oceans of the continent."

WINDS AND CROPS.—When the humid easterly winds extend their influence far into the interior of the country and overpower the dry continental winds, the central and eastern parts of the Gangetic plain bear heavy crops. On the other hand, when the dry west winds of north-west India hold undisputed sway, there are droughts and crop-failures. The victory is now on one side and now on the other, depending on the cold and humid and warm and dry climatic cycles as well as on the seasons of the year. Blanford remarks: "It is a meteorological peculiarity of the United Provinces, that, more than any other part of India, with the sole exception of the arid tract farther west, it is peculiarly subject to vicissitudes of the rainfall." Not to speak of the great famines of the last century, in 1804, 1834, 1838, 1861, 1868 and 1877, these provinces, ordinarily so fertile, have been repeatedly devastated by famine, resulting from the failure of the seasonal rains, and whatever may have been the fate of other portions of the plain, the Ganges Doab has invariably been involved in the disaster in its most severe form. Since 1876-78, famine or scarcity affected the United Provinces in 1891-92, 1896-98, 1899-1901, 1907-08, 1913-14 and 1924-25.

CLIMATE AND CROPPING IN THE PUNJAB—TWO-CROP CONDITIONS.—Of all the Provinces of India the Punjab, which is the most northerly, is also that in which the vicissitudes of climate are greatest. It has the coldest winters, and, together with Sind, the hottest summers. Next to Sind and Western Rajputana, which borders it on the south, it is in great part also the driest province; but in this respect there are great differences in different parts of its area. Much of its south and west is virtually desert, not owing to any want of natural fertility in the

soil—for, wherever, it can be brought under irrigation, no soil is more productive—but solely to the scantiness and uncertainty of the rainfall. But the tract, from 50 to 100 miles broad, that extends along the foot of the Himalaya, receives in most years a rainfall sufficient for successful agriculture; and, since this occurs at two different seasons of the year, *viz.* from January to April and from July to September, two series of crops are raised annually: the spring crops, or *rabi,* consisting chiefly of wheat, barley, and gram, the autumn crops of millet, maize, various pulses, oil-seeds and sugarcane. Cotton, indigo, and some rice are also among the agricultural produce of the Punjab. In the United Provinces the cool season is less cold, less rainy and cloudy, and comes to an end in March, when strong hot winds set in from the west. The rains set in some time in the latter half of June. While they last it rains often more than in the Punjab, but rain is by no means continuous for more than a day or two at a time. The rainfall of the winter season is less frequent than in the Punjab, excepting on the hills of Garhwal and Kumaon. As regards cropping, the same distinction as between spring and winter crops which holds good for the Punjab is also true here; but, while wheat is a dominant crop for the Punjab, forty per cent. of the wheat area of India being found there, the predominance of wheat declines in the United Provinces.

Province.	Total area under wheat.	Percentage of wheat area to total area.	Total area under rice.	Percentage of rice area to total area.
Punjab ..	10,000,000	35	900,000	3
United Provinces ..	7,402,000	30	7,071,917	27
Bihar & Orissa.	1,175,000	4·7	14,652,800	59

Both the Punjab and the United Provinces are exposed to the uncertainties of rainfall. Hence it is in these Provinces that we find the largest development of canal and well irrigation. But danger of famine and scarcity is ever recurrent. A slight variation in the total amount and distribution of rainfall over the months of

the year has extraordinary effects on the fluctuations in the sown acreage under different crops. In proceeding further east to the Gangetic alluvium, we find the density of population increasing steadily. The deltaic portion, though less irrigated, has a more favourable rainfall. In the latter respect there is but little difference between the central and deltaic portions of the Gangetic plain. But in the delta a large area is multi-cropped. The farther we proceed eastward the less irrigation we find, whilst the production of rice becomes far greater.

RAINFALL AND DENSITY.—It has been customary to divide the Indo-Gangetic river basin into several rainfall divisions; *viz.* (1) Punjab East and North; (2) United Provinces East; (3) United Provinces West; (4) Bihar; (5) Bengal; (6) Eastern Bengal. The rainfall is, on the whole, heavier, steadier and of longer duration the farther we move eastward. Owing to the peculiarities in the distribution of pressure there is great variability, and large fluctuations are experienced from year to year. In the region around Sirsa the percentage of variability is as high as 174 per cent., while in Purnea, in Northern Bihar, it is 168.

Basti and Gorakhpur resemble Northern Bihar rather than any other portion of the United Provinces. Here the climate is singularly equable, there is no fierce hot weather, and frost is unknown. The rainfall is as high as that of the neighbouring submontane districts of Bihar. In the Basti district the density per square mile is 737—it exceeds the average figure over the whole of the south district. In Gorakhpur the density on the cultivated square mile reaches as high as 1,100 in Salempur Majhauli, while in pargana Sidhua Jobna it is 845. These figures are little higher than the figures worked out for Allahabad district exclusive of Allahabad city, though in a district like Jullundur it is only the most densely populated *tahsil* which reaches 850. But the corresponding figures to the square mile, including uncultivated as well as cultivated lands, are 890 and 560 as contrasted with 620 and 535 in Allahabad. A density of 650 or 700 is not uncommon in

the eastern districts of Agra or the south-east of Oudh. But, to find a parallel for 890 over so large a rural area, it is necessary to go to congested districts of the Tirhut or Dacca divisions. What especially distinguishes Gorakhpur from the west of the Provinces is that all the land is cultivable, and, what is more, practically all cultivated. Both Basti and Gorakhpur districts are cut off by valleys of many of the rivers which rise in the Himalayas. The Rapti, the Gogra and the Gandak bring fertilising silt as well as annual inundation, as a result of which good crops can grow without irrigation. In the Rapti alluvium an abundant rice crop is annually harvested. Similarly, the Gandak tract, which forms a series of long swamps during the rains, grows an abundant late rice crop. Running along the Gogra is a narrow strip of alluvial *mahals* which, for the most part, grow barley in the rich fields and a mixture, chiefly blue pea, on the poor land.

In travelling further east, towards Bihar, we find this province enjoying a higher average rainfall than the United Provinces. But the rains are liable to occasional failure leading to widespread dearth and famine.

The following table shows the striking contrast of rainfall as between the different parts of the Indo-Gangetic plain.—

	Area in Sq. miles.	Average rainfall Inches.	Local variation Inches.
Punjab Plains ..	120,000	22	6 to 36
United Provinces ..	83,000	36	25 to 50
Bihar ..	30,000	43	39 to 48
Western Bengal: Chota Nagpur ..	38,000	49	43 to 61
Lower Bengal ..	54,000	66	54 to 112

Bihar, a Province Dependent on Rainfall.—The Province of Bihar is divisible into two parts, the one north and the other south of the Ganges. North Bihar is a level alluvial formation, which ordinarily enjoys a copious rainfall, and contains many tracts of great natural fertility. The great rivers, Gandak, Gogra, Kosi, and Ganges have been depositing silt for centuries, and the

districts in North Bihar are composed entirely of alluvial soils. The sources of the Himalayan rivers are far distant from one another and their waters and high floods formerly overflowed the entire country. The Tirhut division is almost a level plain. The embankments along the river banks protect it from inundations; but sluices have been left for the escape during the rains of overflow water, which runs across the region from the Himalayan rivers to the Ganges. It is this inundation which has brought about a very high degree of fertility for this part of Bihar. The average density per square mile for Bihar and Orissa is 454. In the Tirhut division, however, the density rises to more than 800 per square mile, and in Muzaffarpur, which has the highest density of any district in the Province, is actually 969 per square mile. In several *thanas* the density has exceeded 1,000. In the whole of North Bihar the mean density is 696, and in South Bihar 565. South Bihar has a strip of alluvium along the course of the Ganges, but further south the country rises towards the Chota Nagpur plateau and the soil becomes less fertile. With the exception of the Son, the rivers south of the Ganges have by no means so large a drainage area as that of the Himalayan rivers, for they drain only a portion of the Chota Nagpur plateau. Within a short time after the rain they run dry. Away from the Ganges, marshes and lakes are almost unknown. Rainfall is frequently deficient, but is supplemented to a great extent by irrigation. On the whole, well-irrigation has progressed but little in Bihar. In Chota Nagpur, the use of well-water for irrigation is still more limited. In Bihar therefore, whenever rice is grown, the crops fail for want of suitable rains. Bihar has thus a concentrated population in many tracts enjoying a higher rainfall than most of the western Gangetic plain. But, in spite of the advantages of the alluvial deposit, it is subject, like the United Provinces, to occasional failure of rains, and in such seasons has been frequently the seat of disastrous scarcity and famine. Indeed, the agricultural welfare of Bihar is so closely connected with the fluctuations of rain-

fall, in the absence of a widespread irrigation system such as the United Provinces possess, that scarcity and famine are here recurrent much oftener than in the better irrigated districts.

IDEAL AGRICULTURAL CONDITIONS OF BENGAL.—The climate of Bihar is more akin to that of the United Provinces than to that of Lower Bengal, but moister, especially in the eastern districts, and to a certain extent transitional between the two. The climate of Bengal is dominated by the watery character of the surface and its proximity to the Bay, from which winds begin to blow from the coast as early as February and gradually penetrate further inland with increasing heat. The climate of Bengal is as characteristically damp and relaxing as that of North-Western India is the reverse. The dry westerly winds, that play so great a part in the meteorology of the Upper Provinces, are felt only occasionally and intermittently in the province of Bengal during the spring months, and chiefly in the warmest hours of the day; and even then are cooler and of a less parching character owing to the moisture taken up from the surface over which they blow. The agriculture of Bengal is likewise determined by the abundant rainfall and the large number of intersecting channels and streams which constitute the delta. In North-Western India rice is of subordinate importance and an article of luxury. In Bengal it is the universal crop and the food of the people, and two sowings are reaped during the year; *viz.* the *aus* crop sown in the early spring and harvested in July and August, and the *aman* crop which is sown in April, transplanted in August, and reaped in the cold season.[7] Not only is the rainfall abundant, but also it is usually well distributed and is never known to fail. The land of the delta is enriched by yearly deposits of silt. The climate, the soil and the river system are all alike favourable to agricultural productivity and to a phenomenal density of population. Though only two-

(7) Blanford: *The Climates and Weather of India, Ceylon and Burma*, pp. 151-153.

fifths larger than England and Wales. Bengal contains nearly 12 million inhabitants more, the total being more than a quarter as large again.

The concentration of population in Bengal increases the farther we advance along the great rivers eastward. Central Bengal has a density of 566 as compared with 688 in Eastern Bengal. Central Bengal, which is bounded on the west by the Bhagirathi, on the north by the Padma, and on the east by the Madhumati, was formerly the Ganges delta; but it has been gradually raised above flood level, and the great rivers which formerly flowed through it, depositing their fertilising silt, yielding an ample supply of wholesome drinking water, and draining it, have shrunk to insignificance. Their mouths have been silted up and their beds are often higher than the surrounding country, which they are no longer able to drain. The country has become less healthy, and is far less fertile than it was formerly.[8] Eastern Bengal, on the other hand, is hemmed in by the Brahmaputra, the Padma and the Meghna. Where the Brahmaputra rounds the Garo hills, there begins the delta of that river; where the Meghna combines the southern rainfall of the Khasi Hills with the western drainage of the watershed between Bengal and Burma, there begins (in Sylhet) a third delta. The delta of the combined rivers now covers 50,000 square miles.[9] From time immemorial the formation of the great Gangetic delta has been going on by a gradual silting-up process in the beds of the magnificent rivers, which, on nearing the sea, formed a gigantic inland gulf. The Ganges, which in bygone days poured its waters in a southerly direction, has now taken a south-easterly course, forming its junction with the Brahmaputra (Jamuna) close to the point (Goalundo) where the Eastern Bengal Railway terminates at the present day. In the same manner the Brahmaputra, which once poured its torrents below the Garo Hills down

(8) *Bengal Census Report*, 1901.

(9) *Imperial Gazetteer*, Vol. I, page 25.

to its confluence with the Meghna, carrying into the sea all the drainage of the Eastern Himalayas and Assam, has now receded to the west, sending forth its waters into the Padma through the great river named Jenae in the maps, but locally known as Jumna. The great chasm which divided the ancient Barendra and Rarh divisions of Bengal, and which ostensiby was one of the causes which prevented inter-marriages between the castes of Hindus inhabiting them, has thus gradually disappeared, and in its place we have a rich alluvial tract, which, in fertility, is not exceeded by any other country on the face of the globe. It is the annual inundation which governs the cultivator's choice of his fields when sowing his crops. The distribution between high and low land is far more important than that between manured and unmanured land. For the gneissic, laterite, and old alluvial soils are alike mainly dependent on artificial manures to maintain their fertility; whereas the recent alluvium is periodically fertilised by fresh deposit of silt from the overflowing rivers. Very often the practice of depositing silt for the purpose of fertilising the land is resorted to, especially in reclaiming large blocks of marshy and saline soils fit for cultivation. The long continued deposit of mud or silt has gradually raised the level of the river channels above that of the surrounding flats; consequently a low strip of marsh and swamp immediately flanks the river bank on either side, which is submerged when the river is in flood. Beyond these swamps, where the long-stemmed varieties of rice grow abundantly, the ground rises gently on either side of the valley. On account of the ceaseless change in the level of silt-formed plains, *chars* or mud banks and islands form in a kaleidoscopic succession, and the rivers split into innumerable channels, which again throw out their own distributaries right and left. The country so traversed and intersected with waterways, uncontrolled in their meandering, is the true delta. In some places it is a hollow and low-lying tract, which spreads like a vast inland sea. In others it is a wilderness of forest and swamp through which the tortuous streams struggle slowly seaward, constantly throwing up new levels,

pushing out fresh headlands, and everywhere changing the topography of the land surface. At last we reach the great Sundarbans country, a vast marshy forest formed as a result of land-making and encroachment towards the sea on a gigantic scale. But even here the work of reclamation has gone on from the 15th century at a slow but steady pace, and human energy in a continuous fight with jungle has driven the forest life downwards, until at the present day nearly half of what was formerly an unproductive and impenetrable forest waste has been converted into smiling gardens of graceful palm and immense fields of waving rice.

The above bird's-eye view of the river system of Northern India has shown that there is a steady increase of density of population along the course of the Ganges towards the delta. Better soil has been gradually washed from the upper portions of the sloping alluvial plains to the lower portions. Thus we find sand dominating in the Punjab, loam or mixture of sand and clay in the United Provinces, and clay in Bengal. In Bengal we have in addition the annual deposit of the fertile silt of the rivers, streams, and drainage from the northern side of the Himalayas, the Garo and the Khasi Hills, and the watershed between Bengal and Burma. In the case of both the Padma and the Brahmaputra in Bengal, the mean density of population of the districts rises according to their situation along the river's downward course, and this is due to their fertilizing powers increasing with the fall of the level of the land. Secondly, in our journey eastward, we realize progressively a more abundant, better distributed and certain rainfall. The monsoons here consist of a series of depressions which follow each other up the Bay of Bengal. Unlike the peasants of Bihar, the inhabitants of Bengal have no reason to complain of lack of moisture for cultivation. Rice becomes the predominant crop and, towards the fertile semi-aquatic plain, covered by a network of rivers and waterways in East Bengal, we have the valuable money-crop, jute. Thirdly, the delta is more or less subject to an annual inundation.

The Eastern Bengal cultivator is not entirely dependent upon the local rainfall for his food; for the annual floods of the Brahmaputra, the Meghna and the Ganges play a more important part than the rainfall in the fortunes of his crops. Finally, the hot westerly winds which are so detrimental to agriculture in the Punjab and in the United Provinces, and which blow down the Gangetic plain in April and May, do not reach Bengal, with the exception of the outlying districts. Indeed, the river system, the soil and the climate provide agricultural advantages for Bengal to which it is impossible to find a parallel in any plain-region in the world. This is the reason why the deltaic tracts in Bengal show the world's greatest rural density. A compact territory, a part of the most active delta, comprising the districts of Dacca, Faridpur, Tippera and Noakhali has a density between 1000 and 2000; while Bakarganj, on its south, with a density of 834, is fast filling up. The differences that appear in Bengal itself as regards high concentration of population are due only to such ecologic features as the system of internal drainage and the maturity of alluvium.

CHAPTER V.

DISBALANCE OF THE REGION.

Erosion and Ravine Formation.—In our imaginary journey down the river Ganges towards the delta, we observe the rainfall, the climate, the agriculture, the density of population and the culture to improve progressively. It is with filial devotion that the Hindu pronounces the sacred name of the historic river, with an obeisance, as "Mother Ganges." It is significant that agricultural prosperity, which is so closely bound up with the river system, fluctuates with the vicissitudes of the rivers, streams and drainage. Everything points to a steady decline of old alluvial land, and the emergence into prosperity and numbers of new alluvial tracts further towards the delta. Thus the Himalayan rivers, which must once have built up with silt deposit the upper plains of the Gangetic valley, have now cut deep channels in the very plains which they originally formed, and not only cease to fertilise them with fresh deposit, but even erode and gradually but continuously carry away the silt which they originally brought. This work of destruction is assisted by the numerous feeders, which are cutting more deeply every year into the rich layers of deposit, and carrying the most fertile elements of the old silt into the Ganges, Jumna and other large rivers. There goes on in the old alluvial plains a continuous process of destruction and renewal. At each bend the concave bank is being eroded, while the opposite shore receives a new alluvial deposit to fill the void left by the receding river. After a period of years the process is reversed, or the river suddenly cuts a new bed for itself. Between these processes, however, there is an enormous wastage of soil. Sometimes tracts are so much broken by the terracing of ravines which flank the rivers that little but the thinnest stretch of upland fit for cultivation is left in the centre. Such land can only be protected against erosion by terraces and embankments, similar to those in Bundelkhand. The jungle in the

ravines, which with their yawning gullies and fissures present the appearance of an undulating sea, leaves but little room for grazing ground. Often the ravines are destitute of trees. The Chambal-Jumna tract, as a rule, suffers from over-drainage and erosion, and the Chambal river in particular is subject to great and sudden freshets during the monsoon season, when scour causes widespread deterioration of the soil. The ruinous loss of cultivated land will be evident from only one instance, from the Agra district, where in Bah *tahsil* no less than 35·9 per cent. of the whole area is waste, owing mainly to ravine formation. Here the ravines along the Chambal frequently begin to form at a distance of 5 miles or more from the river, and their average length is not less than 2½ miles. Along the rivers, in the immediate vicinity of the stream, there is generally a narrow strip of sloping shore which is subject to alluvion and diluvion. This is known as the "*khadir* tract". Beyond this is the ravine tract, which is absolutely sterile, being most uneven and irregular. Often it is devoid of all vegetation, but sometimes is covered by thorny shrub and bush jungle. Adjacent to the ravines large stretches of land are becoming uncultivable by reason of erosion and scour of the surface soil due to the ravines. The gradual conversion of cultivable land into uncultivable waste due to ravine formation will be evident from a few more examples. In *tahsils* Etawah and Bharthana, district Etawah, which is flanked by the rivers Jumna and the Chambal, there are 41,077 and 40,634 acres respectively of waste land, the proportions being 15·06 and 15·27 per cent. of the total areas. In the district as a whole there are about 1,200,000 acres of ravine land. The wastage has been estimated to be not less than 11 cubic feet of soil per second, equivalent to a steady outflow of earth in a stream 13 feet wide and 2 feet deep, flowing at the rate of 3 miles per hour. From the prevalence of old stone sugar mills, the alignment of the old Mughal Imperial road still to be traced by its *kos* marks, the examination of old wells of known antiquity, as well as from the study of ancient records, it would seem probable that most of the erosion

and ravine formation has occurred during the last 400 years. Along the Jumna, old stone sugar mills are found in thousands. In two villages alone over 600 mills were found, in one 600 and in another over 250. The loss of fertile soil that has been carried from different districts into the larger rivers during the last three or four centuries is incalculable. It is in the Chambal-Jumna tract that the tangle of wild and sterile ravines sloping from the uplands to the river-bank shows its worst features. There is a rough country along the Chambal which drains the native states of Gwalior and Dholpur, and finally, joins the Jumna below Etawah. As far as eye can reach one meets here a labyrinth of rugged ravines and green valleys covered with acacia jungle, every prominent bluff showing the ruins of some robber stronghold. This has been for centuries a "no man's land" occupied by wild Rajput tribes, robbers and raiders by profession, who settled on the flank of the Imperial highway through the Doab and were a thorn in the side of the Mussalman administration.[1]

The process of ravine formation is hastened by the fact that as a result of concentration of population we find in a mature valley very little forest belt left on the banks of the rivers, which might protect them against erosion during the monsoon rains. In all ravine tracts the village communities are accordingly found to check erosion by building dams where the ravines are wide enough, and the sides, too, have often been carefully terraced. Though such areas often provide excellent pasturage for flocks and herds, and have led, as in Etawah, to great development of the dairy industry, yet the stripping of the inadequate vegetative cover by the hungry animals further aggravates the dangers of scour and over-drainage. Thus the gain from cattle-breeding and dairying may be offset by further loss of cultivable land. The ravines present a further danger to the village

(1) Crooke, *North-Western Provinces of India*, p. 26; *District Gazetteers*, Etawah, Agra and Muttra; also *Report on Economic Planning in the United Provinces*.

population in the shelter they easily afford to robbers and bandits, especially in the less accessible portions. The intensity of grazing will be evident from the fact that one million animals graze over 5,000 square miles only in the forests of the United Provinces.

CONTROLLED GRAZING A PREVENTIVE OF EROSION.—Unlimited and continuous grazing kept up for generations cannot but lead to the deterioration of vegetation, thereby facilitating soil erosion. The remedy lies in reducing the number of herds and flocks, and limiting grazing to the amount which forests can stand without detriment. In fact, for the prevention of erosion a system of controlled grazing will be quite adequate. On these lands there is unlimited or uncontrolled grazing of countless herds and flocks, as a result of which the vegetation becomes impoverished after centuries of abuse. There is often a thin covering of scrub jungle, which can absorb hardly any portion of the excess water during the heavy rains. With the hardening effect of the tread of animals and rapid drainage, the monsoon rains penetrate to a depth of a few inches only, and this quickly dries, leaving a soil almost destitute of moisture down to the underground spring-water level, 100 feet or more below. This has reacted very unfavourably on the agricultural population. The gradual loss of fertile lands caused by the extension of ravines along the banks of the Ganges and the Jumna and their tributaries is in the aggregate serious. It has been estimated that the total area of such sterile and inhospitable ravines in the United Provinces alone is 8 million acres. In some of the densely populated districts along the banks of the Ganges, the Jumna and their tributaries, while the enormous pressure of population on the soil has led to a phenomenal expansion of the arable area and shrinking of pastures, there is a considerable proportion of wild, sterile ravine-land entirely denuded of surface soil, exposing beds of *kankar* or hard, brown, barren clay. The increase of such barren land in congested districts contributes not a little towards lowering the standard of living of the peasantry.

SILTING OF RIVERS.—There is another way in which the rivers contribute to agricultural deterioration when the plain reaches maturity. In a flat country, which is but little raised above the sea-level, the rivers, checked by the rising level of the silt-formed plains tend to split into many channels. The distributaries down which the river formerly found its way to the sea degenerate into stagnant lagoons. Many rivers are silted up, while the beds of others are gradually raised by the annual deposition of silt. The silting up of the rivers deprives the country of the fertilising silt it formerly received in generous measure. The main stream of the Bhagirathi was the Saraswati, the river that made the prosperity of Satgaon as a far-famed centre of trade and navigation. Only a narrow and extremely shallow *khal* remains to mark its river-bed. Formerly the Karatoya, the deeper portions of the Atrai, and the Tista were large and deep rivers, affording facilities for navigation and a large export trade. Through the Karatoya in particular was carried on a considerable volume of inland trade and important marts were established on its banks. The Bhagirathi, Jalanghi and the Mathabhanga were also the main distributing channels in Southern Bengal. There was, indeed, an extensive river traffic throughout Bengal which flourished till the middle of the nineteenth century. Large factories were erected by the East India Company on the banks of many of the above-mentioned rivers. Many of these rivers are now silted up, while those which are navigable often bring devastating floods. Rennell surveyed the rivers of Bengal in 1781. Many of the rivers on his map are now hardly traceable. Some have completely changed direction and bed, others have run dry, while still others are choked with vegetation, having scarcely any flow of water. There is at the same time water-logging due to obstruction of the drainage of the country, and malarial fever is rife over the region. This has been the case in the western portions of the Gangetic delta, which compare very unfavourably with those in the east. The Bhagirathi, through which the main current of the Ganges formerly flowed southwards to the sea,

has now become a mere spill channel. In the hot months the connection is lost and miles of sand-banks stand between. The Bhagirathi has been silting up for at least three centuries. Bernier was forced to go overland to Cossimbazar because the sand-bank at its mouth made the river unnavigable.

RESTLESS RIVERS.—Often again, the rivers change their course with great suddenness, and bring about wholesale devastation. The vagaries of some of the Himalayan rivers, such as the Ramganga, the Gogra, the Kosi and the Tista, are to-day a barrier to the expansion of cultivation. Both the Ganges and the Jumna, aged mothers, keep sedately within their beds and only roll wearily from one side to the other. But the rivers just mentioned are gambolling vagabonds; they wander at their own sweet will over many miles of country, carving out beds capriciously for themselves, and leaving them as illogically.[2] But it is in the delta that the rivers become formidable and their frolics cause widespread ruin; they cut away the land in one place and build it up in another in a bioscopic succession, gaily working their way through the friable alluvium behind them, and leaving it high and dry as proof of their contempt for humanity and all its works. The Bhagirathi itself has changed its course several times. The Brahmaputra, the Padma and the Meghna have changed and are still changing. The most remarkable change, which transformed the river system in Northern Bengal was the result of the Tista floods of 1787, when the Tista deserted the Ganges to become a tributary of the Brahmaputra. The variations of population in a district like Noakhali, for instance, in Eastern Bengal, due to the constructive and destructive powers of the great rivers, are extraordinary in their nature.

HUMAN INTERFERENCE WITH NATURE.—Man, again, has aggravated these natural dangers by his unskilful and improvident interference with nature. He denudes the

(2) Sir C. Elliot's comparison while writing of Farrukhabad, quoted in Crook: *The North-Western Provinces of India.*

mountain slopes of forests, thereby rendering his country a prey to drought and flood. His fields and grazing lands encroach upon the banks and head-waters of the rivers. These languish in the hot season or become roaring cataracts during heavy rains. He diverts the main stream of the river into canals constructed without care for the drainage and topography of the region. The whole region becomes water-logged or impregnated with salt; the saturated soil becomes sour, the well-water injurious to health and cultivation, and the climate generally deteriorates. Elsewhere the canal lowers the well-water level, and this leads to contraction of cultivation. In the delta, the marginal embankments built along the banks of the rivers prevent the periodic inundation which formerly renovated fertility. The rivers, now confined to their beds, deposit their silt there and thus gradually raise themselves above the level of the surrounding region. The embankments consequently are raised still higher. This practice, continued for decades, renders the protected country liable to destructive flooding in the event of a breach in the bank. When high embankments are breached during a high flood, the devastation is appalling. In the case of a river like the Gandak, which flows from the Himalayas to the Ganges with a fairly straight course in a single channel, the danger of breaches during a high flood is very great. On the other hand, the presence of flood-banks enables the natural channels to pass a larger proportion of the total flood, so maintaining the integrity of the channels. If there are no flood-banks the chances are that sooner or later the breach in the natural banks will so develop that the original channel will almost cease to function; and the water will take a new course, to the prejudice of the cultivated tract, since it will take many years for the new course to have a definite channel. In the case, however, of the rivers of Lower Bengal and Orissa, the embankments, instead of being useful, are mischievous. In their downward course, the channels gradually decrease in capacity and eventually can pass only a small part of the water during a high flood. Hence escapes are here of great use as safety-valves. The Bhagirathi itself is an

unregulated escape-channel from the Ganges, and has a well-sustained flood season.[3] The absence of outlets or escapes, which are of service as safety-valves, thus increases the risks of inundation. Nor is the occasional inundation detrimental to crops and communications, since the water passes but seldom, and for short periods only. On the other hand, the annual inundation renovates soil fertility, while a railway or road bank constructed parallel to a river may act as a marginal flood-bank; or, put in another way, any effective flood-bank may be used as a road or to carry a railway. Unfortunately, the embankments in Lower Bengal often have no outlets, while the railways or roads, built without any culverts, also obstruct free passage of flood-water. This obstruction has reacted very unfavourably on fertility as well as on the health of the people. A large tract, for example, in Central and Western Bengal, has been deprived of the fertilising silt deposit and become less fertile than before. Everywhere also there is water-logging, causing epidemics of fever. On account of the embankments the beds of some of the old channels have been so raised that they can be drained and cultivated. In summer the channels carry little water and are called dying or dead rivers, constituting a chain of stagnant pools overgrown with weeds. Nearer the sea, however, uncontrolled in its meandering and terrible in its sweep, the river flows back as it were upon man's habitation, flooding the land or sometimes washing it away.

VANISHED FORESTS OF INDIA.—Formerly, the Punjab was covered with a thick forest belt. Forests grew on the Indus—forests yielding timber sufficient to enable Alexander the Great to construct the first Indus flotilla; and about the valley of Peshawar there were wide spaces of water-logged and swampy plain, amid whose thick reed growth the rhinoceros and elephant had their home. There were numerous populous cities and villages in the valley which now lie buried in the sand. Man had no thought for the future. As population multiplied, the

(3) W. A. Inglis: "River Floods considered as a Problem of Indian Administration," *The Asiatic Review*, October 1926.

careless hand of man destroyed trees so prodigally that the natural conditions of the region where formerly vegetation used to flourish suffered disastrous reversion; thus the region dried up and became uninhabitable. Gradually the population shifted from the Indus valley to the central and eastern Punjab, where the rainfall is less deficient. Irrigation has developed here lately; and there are green spots about the Indus river and the newly-spread network of the Punjab canals, which are once again slowly altering the nature of the landscape; but the climate can hardly be changed. In the east and south the Punjab is hot and dry, and from this tract blows across the Gangetic plain the dry hot winds which are so detrimental to crops. In the United Provinces also the injury resulting from the destruction of forest growth and soil erosion is apparent. In the Jumma tract the forests where the Emperor Babar hunted the rhinoceros are now a waterless tangle of ravines, and the beautiful country along the foothills is buried under sand and gravel. By river bed erosion, which has followed the devastation of fire and axe and indiscriminate grazing, the Jumna has been lowered 50 feet during the last 500 years, since the torrents are now unhampered by the roots of the plants and trees which man without discrimination has destroyed. There has also been a corresponding sinking of the water-level. The cold-weather level of the Jumna in the Etawah and Jalaun districts is often 120-200 feet below the general level of the surrounding region. The sinking of the bed of the river is draining the country and the well-water levels are sometimes as low as 200 feet. The banks of the Jumna and the Chambal in the Agra, Etawa and Jalaun districts are now so exhaustively drained that they have become also destitute of vegetation excepting a desert flora, and even this is disappearing. That the forests in the United Provinces have disappeared within the last four or five centuries is not open to doubt. The eastern districts were until the sixteenth century covered with large forest belts. In the *Akbarnamah* it is stated that on the march of an army along the south bank of the Gogra, in what is near the Azamgarh district, forests were traversed and various wild beasts, both land

and aquatic, were seen—a description which is entirely inapplicable at the present day. Finch was told that the journey from Jaunpur to Allahabad was thirty *kos,* "all of which are thorow a continuall Forest." According to the Settlement Report of the Allahabad District, there are practically no jungles now, and those remaining at the last settlement (1874) seem to have disappeared. There is a singular absence of wild life, no doubt a result of the steady extension of cultivation. In Ballia, a considerable portion was waste land at the time of the Permanent Settlement. In Azamgarh, Ballia and Jaunpur districts even pasture lands for cattle are now very deficient. Excepting during the rains and in the alluvial tracts, there is very little grazing and the cattle have to be mostly stall-fed. Even the *dhak* jungles are gradually cut down owing to the demand for wood by sugar-refiners and brick-makers. The destruction of *dhak* trees is followed by an immediate expansion of tillage. In the whole of the United Provinces, of which the area is roughly 100,000 square miles, the forest area amounts to 7,000 square miles or 7 per cent. only. This in itself by all standards is inadequate. Moreover, the great majority of the forests are concentrated in the sparsely-inhabited hills or submontane tract. The destruction of forests and even scrub-jungles still goes on, contributing to the gradual drying up of tanks, *jhils,* and *tals,* and the lowering of the water-level, making irrigation more expensive in districts which cannot depend upon the natural rainfall.

LEVEL OF SATURATION.—In every country a subterranean reservoir exists at a greater or less depth below the surface. It is the level of saturation which, of course, varies from time to time according to the rainfall. At the delta, it coincides with the main tide level, but rises more and more on going inland. It is the level to which wells must be sunk before water appears in them. It is caused by the rain, which is usually said to run off to the extent of one-third; another third sinks in to form this reservoir, and the remainder is lost in evaporation. When following a river valley, one often notices a line of springs

appearing at a certain level; this is when the valley has been cut down to below the subterranean reservoir, which then forms a wet trough for it to run in. When the reverse is the case, *i.e.*, when the river water-level is above the level of the underground water stratum, the river loses a great deal of its water by its percolating into the dry soil around and beneath. In the arid parts of India, this last feature is very common, so that rivers very often become smaller and smaller the farther they go, till at last they dry up altogether. It is a feature characteristic of many parts of the Jumna-Gangetic basin, and it is in this way that the increased aridity brought about by complete destruction of the vegetable cover has led to the capture of smaller streams and made agriculture more and more difficult.

FOREST PROTECTION ESSENTIAL.—It is now admitted that the denudation of trees has cumulative ill effects which tend to reduce the fertility of the country. Forests are most beneficial to fertility and climate. The hotter the climate the more careful man should be to preserve his trees; but, unfortunately, he usually prefers the opposite course, either from ignorance, want of fuel, or shortage of pasture.[4] The denudation of forests tends to decrease the humidity of the air, the equality of temperature and the fertility of the region. Probably the destruction of forests also diminishes local rainfall, since the bare treeless plains when heated tend to check condensation. Further, such destruction speeds up the erosion of the hillsides and thus the silting up of the rivers with the matter washed from the deforested watersheds. In the Ganges plain the annual loss of fertile land due to erosion is incalculable. Not merely is fertile land annually wasted by being washed into streams and rivers, but even the waters themselves, full of mineral matter obtained from the soil-cap of the mountains, have been found to be detrimental to crops. The destruction of forests, if carried on without hindrance, may ultimately affect the extensive irrigation schemes of Northern India. First, forests stabilise mountain stream-flow by acting as huge

(4) Haig: "Trees and Climate," *Discovery*, May, 1923.

sponges retaining heavy rainfall during the summer months. The configuration of the United Provinces makes the problem of regulating the stream-flow important. The protection of the Siwalik forests in the drainage area of the torrents coming down from the south-western declivity of the Siwalik range has contributed not a little to protect the line of the two great canals in the vicinity of the Ganges and the Eastern Jumna canals.

If forests are not protected, it is almost impossible to make irrigation reservoirs owing to the danger of their being silted up quickly by the torrential rainfall of the water from the hills. Again, with the rapid run-off of water from the hills the streams become broader, shift more, and become more torrential, with greater erosive and carrying power. Streams with high velocity and erosive power cannot be utilised for irrigation, even in flat plain. The Siwalik forests have been preserved, much to the benefit of the Upper Ganges and Jumna canal system; but the oak and fir areas of Kumaon and Tehri Garhwal, which affect the vitally important head-waters of the whole Ganges and Sarda river system, have been left unprotected.[5]

EFFECTS OF FOREST AND GRASS-LAND DESTRUCTION.—Lastly, the destruction of forests and indiscriminate extermination of grass-lands increases both floods and droughts, and alters both the time and duration of the river flood, factors of great importance to agricultural prosperity; while the silting up of river-bottoms spells decline of the mature portion of the valley and especially the delta region. Nowhere are forests and grass-lands more important for agriculture than in the tropical and subtropical regions, where the vegetation not only conserves the moisture and ensures fertility by spreading a cover of silt, but also prevents the ground from being over-heated and dessicated by the sun. Deforestation in these regions is particularly harmful in its effects towards upsetting the balance between the factors which determine climate and hydro-

(5) *Report on Agriculture of the United Provinces*, submitted by the Royal Commission on Agriculture.

graphical conditions. The alternation of drought and flood in Northern India is merely a symptom of such loss of ecologic balance, which man has periodically brought about by either excessive increase of numbers or abuse of vegetation in dry and semi-dry areas of the plain.

The great densely populated Gangetic plain is now practically bare of forest growth. It is inevitable that, with the disappearance of the forests, the meteorological conditions of the Gangetic valley will gradually change. It has been estimated that about two-thirds of the water-vapour which is condensed as rainfall over the land is provided by evaporation over the oceans, and the remaining third by evaporation and transpiration over the land. The latter contribution is made up of evaporation of rainfall intercepted by foliage, evaporation from the soil, and transpiration, and estimates are made of these three factors for forest, crops or grassland, and bare soil. The figures are expressed as percentages of an average rainfall of 30 inches a year: for forests they give interception, 15; evaporation from soil, 7; transpiration, 25; total, 47 per cent. For crops, evaporation from soil, 17; transpiratin, 37; total 54 per cent. For bare soil, evaporation 30 per cent. Thus the replacement of forests by field crops or grass-land would tend to increase the supply of moisture to the air and, therefore, the general rainfall slightly; replacement by bare soils would decrease the general rainfall slightly. The changes in the run-off are likely to be more noticeable, replacement of forests by crops would decrease the run-off 15 per cent, and make it less regular; replacement by bare soil would increase the run-off, but would make it highly irregular. A forest 30 feet high may be considered as adding about that amount to the effective height of the ground, and this should increase the local orographical rainfall by 1 or 2 per cent.[6] The role of forest and grass in reducing run-off and erosion has been proved also by studies of Lowdermilk on cultivated field and temple forests in China, in which a ratio of 59: 1 was found. More recently, in the *chaparral*

(6) C. E. P. Brooks: "The Influence of Forests on Rainfall and Run-off," *Metereological Magazine*, December 1927.

of Southern California, Lowdermilk and his associates found a ratio as high as 100.[7] The greater friction of the wind with tree surface compared with open ground is another factor. To this may be added, in favourable mountain situations, an increased supply of water collected mechanically from clouds which envelop the forests. Forests drawing their water-supply from deep sources possibly exercise a slight mitigating effect on droughts. On account of the widespread destruction of forests throughout the heavily populated Ganges valley, the rainfall in some parts is already becoming more scanty and the heat of the hot weather months less tolerable. It is not improbable that in some distant future the Upper Ganges valley may share the fate of the Indus valley, where once there was smiling plenty. The traces of ancient river-beds and sand-buried cities scattered over a vast space in the desert country east of the Indus testify to the gradual desiccation of a once fertile region. The debris and mounds, vestiges of a forgotten civilisation, recently excavated in the sandy deserts of Harappa, whisper a tragedy of famine, despair and abandonment. In the south-western portions of the Doab the desert has already appeared. Further towards the north-west we have the semi-desert tract where can be marked the abandoned bed of one of the greater Punjab rivers, the Hakra, which was a live river probably up to early Muhammadan times, and then lost itself in the sands. It appears that the westering of the Punjab rivers gradually transferred the Sutlej from the Hakra system to the Indus system; the Saraswati and its associated rivers were then unable to maintain a flow to the Hakra channel and dried up. The much-discussed "westering" of the Punjab rivers is due to nothing more than the capture of the rivers in the sands. Thus the Indian desert extends north-east to broad sandy wastes which merge into the scrub-covered plains, characteristic of the south-western portion of the United Provinces. This

(7) W. C. Lowdermilk: "The Changing Evaporation Precipitation Cycles of North China." *Proceedings of the Engineering Society of China*, 1925, quoted by Clements.

region, was formerly productive and well-watered, and contained large and prosperous towns, which are now insignificant and dependent for such prosperity as they enjoy upon modern irrigation canals. The change in meteorological conditions is probably due to long-continued human settlement, extension of cultivation, and contraction of forests which formerly protected the head-waters and drainage area generally of the Hakra, the Sutlej, the Jumna, and their associated rivers. For not far distant is Kurukshetra, which was the first permanent home of the Indo-Aryans, the centre from which their culture gradually spread towards the east and the south-west.

ALKALI LANDS.—There is yet another way in which man has brought injury to himself, making barren what was once a fertile region. Throughout the Gangetic plain, apart from land which has been rendered barren by erosion, there are vast stretches of what are called *usar* lands. These alkali-lands cover about *two million acres* in the United Provinces alone; they are to be found mainly in the country between the Jumna and the Ganges, and between the Ganges and the Gogra. Two particular tracts may be defined in which the barren area forms an exceptionally large portion of the total. The first of these extends from Aligarh to Allahabad, including the districts of Aligarh, Etah, Mainpuri, Farrukhabad, Etawah, Cawnpore, Fatehpur and Allahabad, the proportion reaching a maximum in Mainpuri. The second tract extends from Harodoi to Azamgarh, and includes the districts of Hardoi, Lucknow, Unao, Sultanpur, Pratabgarh, Azamgarh and the north of Jaunpur. Sometimes white salt, which may extend to a depth of some inches, covers the land in the dry season and vegetation may be totally absent. Such plains look like snow-fields dazzling with the *reh* efflorescence which kills everything, eating away even the stone boundary pillars along the canal bank or roadside. But usually the land takes a dry colour, and there may be seen a covering of scanty grass with a single *babul* or strained *nim* tree here and there. The old belief, that alkali soils are the natural consequence of a light

rainfall insufficient to wash out of the land the salts which always form in it by the progressive weathering of the rock powder of which all soils largely consist, is persistently reiterated. Hence alkali-lands are considered to be a natural feature of arid tracts, such as the Punjab and Sind, where the rainfall is very small. These ideas on the origin and occurrence of alkali-land, however, do not correspond with all the facts. Alkali soils are common in the submontane tracts of North Bihar, where the rainfall is between 50 and 60 inches. Howard thinks that a necessary condition of alkali formation is defective soil aeration. Whenever the air supply is cut off by the constant surface irrigation of steep soils, or other causes, alkali salts sooner or later appear. In those tracts of the United Provinces and Bihar where the soil is close in texture, long human settlement has meant an intensive perennial irrigation, coupled with surface tillage. This has produced vast expanses of dead alkali-land.

POPULATION AND LAND EXHAUSTION.—We thus realise that the concentration of population on the fertile alluvial plain itself leads to exhaustion and loss of fertility of the soil in various ways. Even in the most fertile tracts deserts and barren lands appear, reacting most unfavourably upon both the economic condition and the well-being of man. Owing to continuous exhaustion of both tilled and pasture lands, the soil becomes depleted of certain mineral ingredients. In considerable parts of the plain phosphorous is deficient in the soil and the effects of this deficiency on the health of both cattle and human population are far-reaching. Ill-nourished cattle become less efficient for drawing the plough and lifting the water for irrigation, and yield less milk. On account of imperfect cultivation and inadequate manuring, crops suffer both in quality and quantity. Thus fewer animals are kept by the cultivator and he himself sucers from faulty nutrition. Malnutrition pursues its harmful course in an ever-widening vicious circle; the cultivator is too often ill-nourished and a victim to disease brought on commonly by lack of

nourishment; his beasts likewise obtain inadequate nourishment, while both toil wearily in a hopeless effort to extract from the ill-nourished earth enough to keep them from starvation.[8]

RIVER-BASIN ENVIRONMENT.—Man's ignorance and improvidence join with natural causes to check the aggregation of population beyond a certain stage. Thus the population tends to advance along the course of the rivers towards the more fertile region of softer alluvium. Here, again, other dangers face man. When the distributaries that built deltas themselves silt up and lose their connection with the parent river, the delta becomes moribund, and the country becomes gradually unfavourable to human occupation. Nearer the sea, however, there goes on a ceaseless process of land-formation. The rivers build whilst they destroy, and man follows the constructive activity of the meandering distributaries whilst these push out new headlands into the sea. In the different stages of the rivers, the types of human settlement differ. Crops, occupations, density of population and social organisation all vary in the different parts of the river system. The whole texture of man's social and economic life is interwoven with that of the river-system.

Metchnikoff, the Russian geographer, has given us a clear analysis of river-basin environment. The river-basin, he holds, furnishes a synthesis or epitome of all the possible environmental variations and influences. The river, in every country, presents itself to us as a long synthesis of all the complex conditions of climate, soil, configuration and geological constitution of the adjacent territory. Its course, slow or rapid; the volume and the speed of its waters, dependent on rains and snows; the alternation of the seasons, and innumerable other climatic variations; the relief of its basin and the greater or less extension of the seas into which it flows determining the length and the sinuosity of its course; the nature of its

(8) See McCarrison's evidence, *Report of Royal Agricultural Commission*, Vol. I, Pt. II.

bed; the scarcity or prodigality of its alluvial deposits, its organic contents, and the mineral substances that it holds in suspension, rendering its water clear or turbid, imparting to it their properties, colorations and varied tastes and augmenting or diminishing its plastic or destructive power.

We may take his analysis further and apply it to the different parts of the river-basin. In the higher reaches of the river, man was the hunter. His community was small and unstable. Whilst the river comes down from the mountains the pastoralist appears on the scene. The community increases in size but not in stability. On the level plain, where agriculture is the chief source of food supply, the community becomes large and permanent. We find periodical fairs or markets in which forest products or woollen goods are sold at the junction of the valleys. Where the country roads or railroads meet, at the confluences of rivers, or where rivers are easily forded, cities arise. Such cities collect food from the region, and distribute it in wider markets. The size of the city depends on the resources of the region and the facilities of distribution. The river stabilises the human community through its aid to agriculture; as a highway it also keeps man always on the march.

MAN'S RIVERSIDE MARCH TO CIVILISATION.—Whilst the river takes man through a fertile and populous plain towards the sea, a change is brought about in the size of human community and character of civilisation. In the interior the city is a wholesale market-town in the centre of an agricultural region. At the mouth of the river, it becomes a port-town, which may be the distributing centre for an entire continent. In the interior the size and character of an industrial-town are governed by the supply of raw materials and the market organisation of the particular industries located within the region. At the mouth of the river, on account of the facilities of distribution, the city becomes the seat of diversified and multiple industries and the emporium of world commerce.

The river in its different areas exhibits contrasts of resources and facilities of distribution. It exemplifies the ecological process of the supply and distribution of resources which governs both the size and character of the human community. Everywhere the density of population is adjusted to resources. On the mountains a hunting tribe maintains a bare living on roots, herbs, fruits and wild game. In the valley the shepherds and the flocks thrive on the abundant pasturage. On the level plain, the population density of the village community is governed by soil and the supply of water. But, with the development and quickening of transport, it is the case of distribution rather than the local supply of resources which determines the size and structure of the human community. The change in the ecological process produces contrasted types of social and economic life. To give but one or two instances, the conservative population and the stable village communities on the banks of the Jumna and the Ganges in the upper stages are in marked contrast with the floating settlements and itinerant habits of the people of Eastern Bengal. The contrast in types of city is as striking. Cawnpore is an important railway and manufacturing centre in the Gangetic basin, but it has specialised in one or two highly developed industries, while the trade area it commands is local. Calcutta is the centre of more diversified industries and as a port it accumulates goods from Eastern Bengal, Bengal, the United Provinces, the Punjab and Bombay Province and port, and also sends goods to the same areas (excepting Bombay). Again, the upper parts of the river-basin deteriorate while the lower parts exhibit constant growth and renewal. The changes in the fluvial environment, which follow a perfect sequence, produce characteristic rise and fall of the fluvial civilisations, which present a like remarkable regularity. It is thus that the life history of the great historic rivers reflects itself in the successive parts of the river-basin in the sequent development of cultures. The geographical setting of civilisation evolves with the passage of time, the stay-at-home culture of the valley gradually enlarging

itself to a deltaic and then oceanic scale. It is moreover a change from archaic and stationary to progressive conditions. Throughout the march of civilisation, along with that of the river from the interior to the sea, the resources of man have become richer and more complex. Man has also attained to a greater mastery over his river environment. Formerly, the vicissitudes of man's life depended on the natural changes inevitable in the life of the river system. But, with man's gradual growth of mastery of the waters, he controlled and directed the rivers for his varied uses. Irrigation, river transport, flood agriculture, all bespeak man's utilisation of the waters. But by far the most significant development is trade by sea, which ushers in an oceanic civilisation superseding the fluvial. The resources of the latter are narrow and limited. The opportunities which the former affords are as wide as the world.

NEGLECT, PENALTY, AND REPARATION.—For a time thalassic or oceanic civilisation neglects the environments from which man has emerged. In the new world-economy, man neglects the arts of agriculture and brings about soil-exhaustion. Because of soil-depletion fluvial cultures have decayed. The Nile and the Euphrates nourished the civilisations of Egypt and Babylonia, but these fell when the denudation of the hillsides and destruction of the irrigation system led to the decline of agriculture, which ceased to feed the masses. In Rome non-conservative agriculture and the decline of yeoman farming contributed largely to the fall of her civilisation. For commerce man cultivates fewer food crops and more of the raw materials for which the markets clamour. To produce these he adopts the plantation system, which by concentrating itself on one product brings about rapid deterioration of the soil as well as social unsettlement. Agriculture comes to be influenced rather by the state of the markets than by a rotation of crops which replenishes the soil. With the growth of industrial towns in the country itself there is a continual removal of crops and dairy produce, especially the latter, from the villages, and this impoverishes both

soil and pasture. Gradually the cereals and even the cattle food grown on impoverished soils become deficient in nutritive constituents and this reacts on the health of men as well as of farm animals in both village and city. In timber camps, again, men revel in bringing down the forests by fire and axe. In the commercial age, railways, harbours, roads and all the machinery of land transport are improved beyond recognition, but water transport and trade are abandoned to neglect. Rivers and waterways are allowed to deteriorate till they become unfit for navigation. Thus the need of the regulation of the flow of the rivers, the cleaning of their channels, and the prevention of silting up are brought home to the merchant. It takes years of agricultural decline and rural unsettlement for man to realise that his reckless methods will for ever discredit his generation in the eyes of generations to come. When this dawns on him he repents his agricultural prodigality, and endeavours to atone for his graceless past. No longer is he concerned merely with the merchandise of commerce. For commerce and industry ultimately depend on the agriculture, the arts and the standard of living of the teeming millions. The oceanic civilisation, in brief, has learned that it cannot afford to neglect the forest and the valley environments. The inter-connection and the inter-relation between the different sections of the river-basin with the typical stages of culture are now emphasised. Reafforested planations, verdant pastures, fertile fields and worldwide markets all go together. On the other hand, agricultural decline follows from deforestation in the heights, the neglect of pastures, the decline of water-supply, or, again, the robbery of the soil by inefficient farming methods or by the succession of a money-crop governed by the needs of the world market irrespective of the needs of soil preservation. Man always and everywhere pays the penalty of disturbing the ecologic equilibrium. On an old and densely peopled alluvial plain, where the adaptation of crops and farm practice to soil, climate, and water supply is very close, the natural decline of rivers and soil deple-

tion and interference in the ecological complex brought about by human and cattle factors lead to the decline of ancient seats of civilization.

RESTORATION OF BALANCE.—Scientific agriculture, afforestation, as well as judicious terracing and construction of embankments which protect riverine soil against erosion, the shift from the grain type of agriculture to the crop-tree type on land which is too arid, steep or rocky for continuous successful cultivation, the gradual cultivation of defensive vegetation on sand-dunes and the reclamation of *usar* lands by suitable cropping, are some of man's recent efforts to enter into an alliance with the vegetable world for improvement of a difficult agricultural situation. Similarly, the study of hydrographical conditions in the different parts of the river basin gradually leads to a more scientific well and canal irrigation, the improvement of drainage, the regulation of rivers and minor streams, and the development of fisheries, all of which react favourably upon agricultural economy. Man, tree, and water cannot be regarded as separate and independent entities. It is their interworking that is everywhere discernible on the surface of the land and in the life and manners of man. Man has, indeed, learnt by trial and error that his life is inextricably interwoven with water, trees, and animals. If he commits crime against these, he lets loose destructive forces, which ultimately engulf his carefully-wrought handiwork, his civilisation. On the other hand, in the natural balance of man with the organic and inorganic world around him, lie his security, well-being and progress.

CHAPTER VI.

HUMAN INTERFERENCE WITH PLANT ECONOMY.

INTERACTION OF PLANT AND ANIMAL COMMUNITIES. —The human community and the plant community are not two independent factors. When man has long inhabited a given region, its vegetation and himself have come to a balanced relationship. Many plants man directly destroys. Other plants he destroys indirectly as when he grazes his herds of cattle, sheep, and goats, or ruthlessly razes to the ground the protecting forest cover. Again, in his progress from the hunting and pastoral to the agricultural stage, man modifies the soil and deliberately or inadvertently introduces new plants and improves their living conditions. Incidentally, some of the native plants are eliminated in competition with the latter; while new plant communities spring up and thrive with the aid of artificial conditions brought about by human civilisation; such, for instance, as the introduction of irrigation systems on an extensive scale that alters *inter alia* the edaphic as well as biotic factors of the region. When agriculture becomes more intensive and industries develop, more profound changes take place in the vegetation. It is a ceaseless interaction between plant and animal communities which is visible everywhere on the surface of the earth.

MAN'S REGIONAL COMPLEX.—Just as plant and animal communities are determined not merely by their physical environment but also by their relations to one another, so the human community is determined not merely by the physiography and climate of the habitat but also by the plant and animal communities, with which it constitutes the regional complex. As man's economic life progresses,

there is more and more intensive utilisation of natural resources. This leads to a more widespread destruction of many valuable indigenous plants and to a further retrogression in vegetation. On the other hand, where man is primitive or suffers a setback as a result of war and disease, for instance, the vegetation at once passes to a more advanced stage, leading to its full climatic expression in that region, if no inhibitive forces impede its progress. At every stage the vegetation is interfered with by the biotic factors. Sometimes the effects of these may be so profound that the older system may not be discernible at all, its place now being taken by an entirely new seral unit. Everywhere there goes on the struggle between the animal and the vegetable communities. The balance that is established between them is being continuously upset, continuously restored.

BALANCE OF MAN AND VEGETATION ILLUSTRATED.—Nowhere is this interaction between man and vegetation so vividly illustrated over an extensive area than in the Gangetic plain. The balance between the progressive tendencies of vegetation and the retrogressive influence of man is nowhere more evident than in the vegetation of this region. Throughout the Gangetic plain vegetation may be said to have attained now on the whole an apparent equilibrium in relation to variations in rainfall and temperature which at any moment is liable to be upset, so that it is likely that the pre-existing stages of the plant succession would be reverted to as a result of the withdrawal of the intensive biotic interferences caused both by cattle and human concentration in this region.

FLORA OF THE GANGETIC UPPER PLAIN.—In the Upper Plain, where the rainfall is under 30 inches, vegetation is scanty, the trees and shrubs being mostly thorny, and a number of desert plants occur such as *Alhagi maurorum*, *Capparis aphylla*, *Prosopis spicigera*, *Tecoma undulata*, *Salvadora persica*, *Salsola Kali*, together with species of *Grewia* and *Acacia*. Some of these extend eastwards, as, for instance, *Salvadora persica*, which has been found along the sand-dunes and arid areas from the Punjab to

the United Provinces. It occurs in Agra and Etawah districts and then again along the railway line on sandy tracts between Cawnpore and Lucknow, where it abruptly stops. Likewise, *Prosopis spicigera* extends further towards the middle Gangetic plain. *Alhagi maurorum* forms dense patches on sandy tracts on the banks of the Ganges at Allahabad.

We have already referred to the gradual increase of arid conditions in the south-western part. Some of the elements of the Perso-Arabian flora which are denizens of the desert regions of Western India thus extend themselves towards the very centre of the Gangetic plain. In many tracts the flora is tending to be transformed into a xerophytic type. Some of the districts, such as Agra, Muttra, and Etawah, are remarkable for the absence of trees. It appears that there were formerly large forests that covered these tracts, but these have been cleared within the last four centuries. Remnants of the pre-existing deciduous vegetation still linger, though often in dwarfed and stunted condition, owing to the free use of man's axe and indiscriminate browsing by his live stock. Such, for instance, are *Casearia tomentosa, Butea frondosa* (*dhak*), *Ailanthus excelsa, Woodfordia floribunda, Acacia leucophlaea.* In the cultivated plains the tamarind (*Tamarindus indica*), *nim* (*Melia Azadirachta*), and *mahua* (*Bassia latifolia*) are commonly found as a result of man's selection and protection. The *babul* (*Acacia arabica*) is quite common in places, while *khair* (*Acacia Catechu*) usually grows in the riverain tracts. Plantations of *babul* by village communities as well as by the landlords are familiar features. In some cases the Forest Department has undertaken extensive planting of *babul* trees. Patches of *dhak* (*Butea frondosa*) in the vicinity of villages in the interior are in some cases supposed to be the vestigial remains of old forests which have been cut down and cultivated, while in others these have been deliberately planted for purposes of fuel and the tanning materials yielded by the bark and fruit. In many localities the relaxation of cultivation leads to the *ecesis*

of a particular kind of grass called *"kans,"* which is a great pest, often recurring in cycles. It may spread rapidly and thus may finally stop the plough. After a period of 10 or 15 years, *kans* gradually gives way to other herbage and grasses, and the land may again be brought under cultivation. Again, where man alters the conditions of agricultural water-supply and natural drainage by introducing canals, species of swamp flora characteristic of inland Indian marshes and lakes make their appearance. In some areas salt encrustation and water-logging have thrown back the boundary of human settlement by producing conditions which favour the formation of extensive barren stretches of land of strongly alkaline nature, usually called *usar,* which tend gradually to encroach on cultivated land.

SAVANNAH FLORA.—Generally speaking, however, the vegetation as at present prevailing is savannah-like throughout the densely populated area, while patches of deciduous forests, probably remnants of the older more extensive woodlands, are found in the *Terai* districts and in those parts of the valley where the rainfall is over 80 inches. As a result of the enormous pressure of population in the fertile valley and the increase of landless labourers outside the forest zone, colonies of settlers filter through the forest barrier and extend the limits of cultivation into the interior of the forest. The destruction of forests by axe and fire for the production of patches of grassland for cattle and the later introduction of brand tillage, along with a system of nomadic, intermittent cultivation, completely upset the balance so far subsisting between human population and semi-natural vegetation. As the plough gets the upper hand, the forest yields before the onslaught both of man and beast. The savannah formation, which is the general factor of vegetation at present, is represented by species like *Terminalia tomentosa, Anogeissus latifolia, Diospyros melonoxylon, Morinda tinctoria, Odina Wodier, Holarrhena antidysenterica* and *Nyctanthes Arbortristis, Lagerstroemia parviflora, Buchanania latifolia, Bassia latifolia, Flacourtia*

Ramontchi, along with shrubs like *Carissa Carandas.* The "thorn savannah" in the same way consists largely of *Zizyphus rotundifolia, Gymnosporia montana, Cassia auriculata, Capparis sepiario, Carissa spinarum, Acacia leucophlaea Alangium Lamarckii, Prosopis spicigera* and others, all common enough on the dry hills of Bundelkhand and the Central Provinces, many of them extending to the Deccan.

SEASONAL VARIATIONS.—There is a well-marked periodicity in the vegetation of the greater part of the Ganges valley, corresponding to the seasonal variations characteristic of the climate of the region. During the rains, as a result of excessive soil moisture and high humidity, a dense carpet of rainy season plants covers the land. This is also the season of wet crop cultivation, rice, maize and sugarcane being the mainstay of the peasant at this time.

With the advent of winter, the relatively lower temperatures prevalent in the night and large diurnal range of temperature exercise a selective influence on the growth of herbaceous vegetation. The life cycle of rainy flora comes to an end, and we have now other plants taking their place. S. K. Mukerjee has shown[1] that the aerial parts of some of the representative perennial species of the rainy flora die down to the ground at the beginning of winter, when a fresh crop of shoots arises from the root-stocks in the region of the ground level. These winter season shoots show a marked difference both in their morphological and physiological characters from those of the rainy season. Thus there is a greater development of cork, and clothing of hairs, as well as deposition of tannous and resinous material in the tissues in the winter season shoots, thereby enabling the plant to stand better the climatic influences prevailing in winter. These latter in their turn are shed at the advent of the dry summer season, when conditions of life materially alter. Henceforward practically all traces of herbaceous plants composing the rainy season and winter season flora

(1) *Proceedings of the Indian Science Congress, Calcutta,* 1920.

are obliterated. Many of these, however, may perennate below the surface of the soil by means of underground perennating organs. A fresh cycle of summer season vegetation now makes its appearance. The aerial shoots of the perennial plants composing the flora show features of adaptation to new conditions of life consequent on the introduction of extremes of climatic conditions which manifest themselves in the form of strong hot winds, extremely high temperatures (100°C.), marked aridity of the soil, extremely low humidity, strong insolation, etc.

DENSITY, CULTIVATION, AND RAINFALL.—We have already referred to the concentration of population in the Ganges Valley and resultant progressive increase of arable area at the expenses of former widely extending natural forest formations. The expansion of cultivation still proceeds apace, while excessive grazing has been going on for centuries in a region which can hardly set apart cultivated land for the growth of fodder crops. The following table shows the density of population, the percentage of cultivated to cultivable area, and the average rainfall.

Natural Division	Rural Density per sq. mile	Percentage of cultivated to cultivable area	Rainfall
Sub-Himalaya, West	374	98·7	40
Indo-Gangetic Plain, West	459	103·7	30
Indo-Gangetic Plain, Central	504	109·0	35
Central India Plateau	189	83·3	32
Sub-Himalaya, East	624	122·0	45
Indo-Gangetic Plain, East	686	110·8	40

LIVE STOCK.—In addition to the human population there is a large number of cattle and buffaloes, sheep, goats, horses and donkeys, which depend for their food mostly on the vegetation. The following table shows the number of cattle in typical districts in the United Provinces.

Districts	Head per 100 acres
Gorakhpur	421
Aligarh	395
Jaunpur	373
Gonda	367
Meerut	358
Partabgarh	353
Ghazipur	298
Rae Bareli	267

Districts.	Head per 100 acres.
Cawnpore	253
Muzaffarnagar	239
Shahjahanpur	201
Kheri	174
Banda	135
Mirzapur	105
Jhansi	60
Total Province (excluding hill)	206

VEGETATION MODIFIED BY GRAZING.—In heavily grazed areas the vegetation is frequently reduced to one or a few species that are avoided by cattle, among which may be mentioned *Butea frondosa, Holarrhena antidysenterica, Casearia tomentosa, Lagerstroemia parviflora, Woodfordia floribunda, Adhatoda Vasica* and many *Euphorbiaceae,* including *Euphorbia* spp., and *Jatropha* spp. Species of *Zizyphus,* such as *Z. Jujuba* and *Z. rotundifolia,* often form a dense shrubby growth on heavily grazed areas, where it affords protection to the seedlings of trees and enables them to establish themselves. In parts of the United and Central Provinces heavy grazing as well as arid conditions have so favoured the prickly scrambling *Zizyphus Oenoplia* that it forms dense impenetrable masses.[2] In the Upper Gangetic plain during the dry season cattle power is in greater demand for irrigation. Under conditions of indiscriminate grazing, all grasses excepting those which grow on *usar* lands are grazed to the ground-level, and trampled under foot. The result is that at the height of the dry summer season, when there is great demand for draught in connection with agriculture and irrigation, no pasturage is left and the ground is practically destitute of herbaceous vegetation. The *babul* (*Acacia arabica*), so common in the uncultivated waste-land areas can, however, withstand the rigorous biotic pressure. The cattle generally avoid it, only pods being readily eaten by sheep, goats, and even cattle. It is said that the ejected seeds germinate more readily than those which have not been so swallowed. Thus the tree multiplies, especially in the dry tracts and on river banks, where the vegetation is exposed to the biotic interference of man and his flocks and herds.

(2) Tansley and Chipp: *Aims and Methods in the Study of Vegetation,* Chapter XV.

EFFECT OF HUMAN ACTIVITIES ON VEGETATION.—The combined effect of all the activities of man has thus been gradually to depress the natural vegetation from the original climatic climax monsoon deciduous forest, through a series of stages, to the open dry grass-land making up the grazing areas of the present time, with here and there remnants of resistant woody plants—which led Schimper to call the Plains formation "thorn-scrub". These remnants function as pioneers, wherever human pressure is lessened, and anything like succession is permitted to go on. The thorn-scrub stage probably does not correspond exactly to any stage in normal succession, and the dry grass-land almost certainly does not. The retrogressive succession is *not* the reverse of the normal progressive succession.

Vegetation may be said always to be balanced against the activities of man. The denser the human population, the greater the destruction of the natural vegetation, and the greater the depression of the vegetation from the original climatic climax. Careful cultivation completely destroys all natural vegetation. Repeated felling destroys all woody plants that cannot coppice freely. Grazing eliminates less resistant herbaceous plants, and all woody plants except those with edible leaves, and those unusually well protected by thorns. Brand tillage probably has been an important factor till recent times. On the Plains the vegetation is now rather delicately balanced against man at about the dry grass-land or the thorn-scrub stage. The soil over most of the Indo-Gangetic Plain seems to be supporting about all the human and bovine life that is possible under existing methods of exploitation. Increase in intensity of exploitation results in further destruction of natural vegetation and the amount and character of the vegetation sets a limit to the amount of animal life. Relaxation of pressure immediately results in a movement of the vegetation towards the climax. But no relaxation is possible under present conditions. Dry grass-land and thorn-scrub formations remain practically stationary.

PLANTS ELIMINATED BY EXPLOITATION.—On the next page is a list of plants found on the area, arranged in appro-

ximately the order of their elimination under increasingly severe exploitation. Over-exploitation eliminates practically all of the valuable forage plants, and their place is taken by comparatively worthless annuals, which die and leave the ground almost bare at the time forage is most needed, the hot season. *Aristida Adscenscionis* is the indicator of over-grazing.

That the present vegetation is not the climatic climax, but a greatly depressed stage due to human activities, is indicated by the immediate and striking recovery on protection. Inaccessible ravine banks, thickets of thorny shrubs, and even ordinary areas bear scattered individuals of valuable grasses and other forage plants, ready and waiting for the opportunity to replenish the over-grazed areas. Military grass farms, parks, ond other enclosed and protected areas, show the direction, rapidity and extent of recovery toward the climax.

On a heavily grazed area we notice:

1. Gradual elimination of valuable species under increasingly heavy grazing.

2. The annual characteristic of over-grazing—*Aristida Adscenscionis, Melilotus indica, Cassia obtusifolia.*

3. The woody plants characteristic of the survival of thorn-scrub.

4. The characteristic and uniform growth habit of the dry grass-land plants, belonging to a wide range of families.

Plants of the Phaphamau area, with the plants in the first two lists arranged approximately in the order of their elimination under increasingly severe exploitation.[3]

WOODY PLANTS.

	Pioneer Forest	Thorn scrub	Dry Grass land	Over-Grazed area	Dry Grass land protected
Morinda tinctoria. (Rubiaceae) ..	X	X			
Holoptelea integrifolia. (Ulmaceae) .	X	X			
Casearia tomentosa. (Samydaceae) ..	..	X			
Butea frondosa. (Papilionaceae) ..	X	X			

(3) I owe this table to the courtesy of the late Principal Dudgeon, Ewing Christian College, Allahabad. A Contribution to the Ecology of the Upper Gangetic Plain, *Journal of the Indian Botanical Society*, Vol. I, pp. 296-324, 1920, has also supplied valuable data.

	Pioneer Forest	Thorn scrub	Dry Grass land	Over-grazed area	Dry Grass land Protected
Carissa spinarum. (Apocynaceae) ..	X	X			
Zizyphus Jujuba. (Rhamneae) ..	..	X			
Streblus asper. (Urticaceae) ..	..	X			
Flacourtia sepiaria. (Bixaceae) ..	X	X			
Cocculus villosus. (Menispermaceae) ..	X	X			
Balanites aegyptiaca. (Simarubaceae)	..	X			
Acacia leucophlaca. (Mimoseae) ..	..	X			
Acacia arabica. (Mimoseae) ..	..	X			
Capparis sepiaria. (Capparideae) ..	..	X			
Alangium Lamarckii. (Cornaceae) ..	..	X			
Jatropha gossypifolia. (Euphorbiaceae) ..	..	X			
Justicia adhatoda. (Acanthaceae) ..					
PERENNIAL HERBACEOUS PLANTS.					
Apluda varia. (Gramineae) ..	X	X	..	..	X
Andropogon contortus. (Gramineae) ..	X	X	..	..	X
Cenchrus biflorus. (Gramineae) ..	X	X	..	..	X
Rhynchosia minima (Papilionaceae).	X	..	..	..	X
Pennisetum cenchroides (Gramineae) ..	X	X	..	..	X
Alysicarpus monilifer. (Papilionaceae) ..	X	X	..	..	X
Indigofera linifolia. (Papilionaceae).	X	X	X	..	X
Paspalum sanguinale. (Gramineae) .	X	X	X	..	X
Tephrosia purpurea. (Papilionaceae).	..	X	X	..	..
Desmodium triflorum. (Papilionaceae) ..	..	..	X	..	..
Calotropis procera. (Asclepiadaceae)	..	X	X	..	..
Cynodon dactylon. (Gramineae) ..	..	X	X	..	..
Boerhaavia diffusa (Nyctaginaceae) .	..	..	X	..	..
Vernonia cinerea. (Compositae) ..	..	X	X	X	..
Indigofera enneaphylla. (Papilionaceae) ..	X	X	X	..	X
Heliotropium strigosum. (Boragineae) ..	..	..	X	X	..
Polygala crotalarioides. (Polygalaceae) ..	..	..	X	..	..
Launaea nudicaulis. (Compositae) ..	..	..	X	..	..
Evolvulus alsinoides. (Convolvulaceae) ..	..	..	X	X	..
Convolvulus pluricaulis (convolvulaceae) ..	..	..	X	X	..
Eleusine aegyptiaca. (Gramineae) ..	X	X	X	..	X
Justicia simplex. (Acanthaceae) ..	..	X	X	X	..
Euphorbia hirta. (Euphorbiaceae) ..	..	X	X	X	..
Eclipta erecta. (Compositae) ..	..	..	X	X	..
Andropogon annulatus. (Gramineae) ..	X	X	X	X	X
Andropogon intermedius. (Gramineae) ..	X	X	X	X	X
Panicum javanicum. (Gramineae) ..	X	X	X	X	X
Cyperus rotundus. (Cyperaceae) ..	..	..	X	X	..
Cyperus compressus. (Cyperaceae) ..	..	..	X	X	..

	Pioneer Forest	Thorn scrub	Dry Grass land	Over-grazed area	Dry land Grass Protected
Euphorbia granulata. (Euphorbiaceae) ..	..	..	X	X	..
Corchorus Antichorus. (Tiliaceae) ..	..	..	X	X	..
Lepidagathis trinervis. (Acanthaceae) ..	..	..	X	X	..
ANNUAL GRASSES ON HEAVILY GRAZED AREAS.					
Eragrostis tenella ..	..	..	..	X	..
Eragrostis Willdenoviana ..	..	..	X	X	..
Tragus racemosus ..	..	..	X	X	..
Oropetium Thomaeum ..	..	..	X	X	..
ANNUALS CHARACTERISTIC OF SEVERE OVER-GRAZING.					
Melilotus indica. (Papilionaceae) ..	..	..	..	X	..
Cassia obtusifolia. (Caesalpineae) ..	..	..	..	X	..
Aristida Adscenscionis. (Gramineae) ..	..	..	..	X	..

HILLSIDE CULTIVATION AND OVER-GRAZING.—With increase of population grazing and cultivation ascend the hillsides. When we reach a certain altitude a reverse movement also is seen, *viz.*, the descent of hillmen for pasturage and intermittent cultivation in the valleys during winter. In the hills uncontrolled grazing often would be seen to affect the natural regeneration of forest communities. It effectually keeps down the seedlings of most trees and facilitates the invasion of grass-lands over woodland areas. The supersession of forest by grass-land may or may not be useful to man in his economic climb. The forest might have been more valuable for the supply of timber and various other forest products when a community had reached the industrial stage. The invasion of the grass-land by the cutting and burning of forests, again, may react unfavourably upon cattle, when the trees comprising the forest community are such that they yield twigs and leaves which serve as useful fodder. If severe and indiscriminate grazing be continued, it leads to the destruction of the nutritious grasses and throws the vegetation back to a worthless weed stage which has to be left alone for some time if the former types are to return. It is possible to work out a system of restricted and rotational grazing which keeps the vegetation in the most valuable stages. But this is possible only as a result

of a thorough study of the vegetative succession in a given area. Often the destruction of the surface humus following over-grazing on the hill-slopes subject to torrential downpour leads to soil erosion, and exposes the bare subsoil, which may sometimes be rocky in nature. We have already pointed out that the destruction of forest canopy and consequent soil erosion in regions of high rainfall are the fertile causes of floods in the lower reaches of the rivers. Thus not merely cultivation in the hills but also agriculture in the lower valleys suffer on account of man's reckless improvidence.

JHUM CULTIVATION.—On the hillsides cultivators who confine themselves to local cultivation round their hamlets in the valleys hardly influence the wild vegetation beyond those limits. On the other hand, when they adopt the practice of nomadic agriculture they alter the character of the forest over great tracts of country. In India the practice known as shifting cultivation (*jhum*) is responsible for the extensive destruction of tracts of original forest and for the appearance of grass-lands. Troup has described this system and its effects as follows. Under this system of cultivation patches of forest are cleared and burnt, field crops are raised on the clearings, generally for two or three years, sometimes for a longer period, and the clearings are then abandoned. Where the population is scanty it may be many years before the same patch of forest is again cleared; but, where the population is dense and the area of forest is limited, the interval between clearings may be only a few years, in which case the forest deteriorates and much harm is done by erosion. The vegetation springing up on the abandoned clearings varies: in some cases it consists of tree growth following on a temporary herbaceous growth, in others of bamboos alone, in others of grasses. The precise conditions under which wood-land or grass-land respectively succeeds forest cleared for grazing, shifting, or permanent cultivation, need closer investigation. Among the more important factors appear to be the amount and distribution of rainfall, the various physico-chemical factors of the soil, the

nature of the forest, the surrounding vegetation, the length of time for which the clearing is cultivated, and the intensity of biotic interference depending on the character of the human settlement.

DESTRUCTIVE POTATO CULTURE.—In the districts of Naini Tal and Almora in Kumaon the denudation of the hillsides which has followed the expansion of the cultivated area, mainly for potato cultivation, has become a serious problem. The method adopted by the cultivators was to clear a patch of forest and then to utilise the virgin soil for growing potatoes. This patch became exhausted after a few crops had been harvested, and then the process would be repeated, so that one village would clear a whole hillside within a few decades: the more so since they found the occupation very lucrative compared with the results obtained from the ordinary forms of agriculture. The increase of the population, as well as the development of the railways, tendered to create a demand for potatoes, and the ease with which they can be grown made the crop a favourite with the hill people. Potatoes are not merely a much needed provision during winter, but also are a heavy-yielding money-crop which can invariably be sold when there is a surplus left over domestic consumption. Potato cultivation now stretches over hundreds of acres of land which were formerly covered by forest growth. In many parts, the hillsides have been laid completely bare. The stripping of the hillsides and the preparation of the soil for potato cultivation result in the loosening of the upper strata of the soil, which often stand in danger of being washed away by heavy downpours of rain. Thus large areas of valuable *talaon* land have gone to utter ruin, and what was once a fertile valley has become nothing but a boulder-strewn torrent-bed, the sub-soil or the rock matrix, as the case may be, being exposed to the erosive effects of the elements.[4]

FOREST FIRES.—The invasion by the human settlement is responsible in yet other ways for a complete alteration of

(4) *Naini Tal District Gazetteer*, p. 30. Vide also Geology and Forest Distribution, Indian Forest, 1919.

the original forest type over large areas. Throughout the sub-Himalayan tract severe fires were formerly regular and widespread in the dry season. Fires are taking place at the present day in tracts where fire protection is not introduced. The hillman burns the dry grass in order that grazing may improve at the advent of the monsoon. Such fires spread from tall grasses to the trees, and are carried from forest to forest by the high wind, till they become difficult to control, much more to conquer. Some species of forest trees, such as *Pinus longifolia, Shorea robusta* and *Tectona grandis,* are able to resist fire, provided they have attained a certain maturity and age. Thus in the deciduous forest no fire, unless helped by trimmings at the bases of the trees, can kill *Pinus longifolia,* which is over 100 feet high, and these large trees will reseed the area.[5] But repeated burnings lead to prevention of the return of the original forest and the occupation of the ground by species which are more fire-resisting.

GRASS-LANDS AND HUMAN INTERFERENCE.—We thus realise the enormous change brought about in the natural vegetation of India as a result of intensive human interference. The supersession of grass-lands by forests, if and when protected from fire, indicates that the grass-land comes into existence as a result of successive generations of pastoral and agricultural peoples, exercising a decisive influence in the process of natural succession. Troup gives evidence pointing to the fact that, at the lower elevation at all events, India is primarily a forest country, and that most of the extensive grass-lands have been the product of biotic factors. Even at the lower elevations, however, natural grass-lands are to be found, particularly on old swamps and river-beds which have partly or wholly dried up; but these are probably not permanent but seral stages, and may be expected in time to become clothed with tree growth. At high elevations, where tree growth is absent as a result of a number of ecological factors, grass-lands of an apparently permanent character are to be found.

(5) Champion: "Observations on some effects of fires in *Chir* (*Pinus longifolia*) Forests of the West Almorah Division." Vide also Dudgeon's article on The Ecology of Tehri-Garhwal, J.I.B.S. Vol. IV, 1975.

FODDER PLANTS AND SCRUB JUNGLE.—Throughout the year, and especially during the dry season, in the more densely populated regions of the Gangetic plain, on the outskirts of cultivated areas and in moister localities, all grasses and associated plants are cut off just below the soil surface for fodder. The animals are set free on most of the uncultivated land or on fields after the harvests, and constantly eat grasses down to the soil surface. It is only the most persistent perennials which can survive under such conditions. Doob grass (*Cynodon dactylon*) comes up in abundance after having suppressed the other coarser grasses. Almost ninety per cent. of the cattle population in the towns depends on this grass, and a large class of agricultural labourers have taken to the occupation of grass-cutting for supply to the fodder market. Moreover, since the forest area in the densely populated districts has been mostly exterminated, man depends for fuel on a number of xerophytic shrubs and stunted trees, which are periodically cut down to the ground level. These in due course shoot forth into a kind of scrub jungle. The main constituents of scrub jungle are *Butea frondosa, Streblus asper, Carissa spinarum,* etc., which are frequently met with in all parts of the Gangetic plain. Other important species are *Capparis sepiaria, L., Acacia arabica,* Willd., *A. leucophlaea,* Willd, *Balanites aegyptiaca,* Delile, *Justicia adhatoda* L., *Flacourtia sepiaria Roxb., Zizyphus Jujuba Lamk., Zizyphus rotundifolia* and *Alangium Lamarckii,* Thw. The *dhak* jungles are of considerable value to the villagers on account of the fuel they supply and the leaves, which are used for making cups and platters. But these are of little use as fodder reserves, since the soil is generally too poor for the growth of good grasses for cattle.

THORN PRODUCTION BY GRAZING.—Many of the above plants are conspicuously thorny, and are thus protected from total destruction by grazing animals. In this connection it may be mentioned that a special adaptative feature has been observed between the incidence of grazing and the production of thorns in plants such as *Casearia*

tomentosa, Alangium Lamarckii and others. As a result of intensive grazing by cattle, goats and sheep, the lower portions of these plants, within easy reach of the animals, assume a rounded shape in the lower region, in which the branches are densely and tightly packed up, while the terminal portions of the twigs and branches are converted into thorns. This seems to be an ideal method by which such plants are able to ward off the attack of intruders and thus avert the danger of extermination of the species, which naturally follows from the heavy concentration of human and cattle enemies. From the normal luxuriant growth seen in the upper regions of these plants beyond the reach of grazing animals, where the branches spread out and are relatively less thorny, it would appear as if the trees are mocking at the discomfiture of the animals.

DRY MEADOW VEGETATION.—Where the area is more arid and at the same time subjected to the retrogressive influence of more intense human factors, the vegetation is neither the thorn forest nor even the thorn-scrub stage, but is the dry meadow so commonly seen in the Upper Ganges Valley. This is composed of such perennial grasses, among others, as *Andropogon intermedius* Br., and *Eleusine aegyptiaca* Desf., which produce a luxuriant grass cover, and under severe grazing conditions assume a dense, compact and tufted habit as the result of propagation by runners. According to Dudgeon the typical dry meadow has now become characteristic of most of the Upper Gangetic plain. Overgrazing and the intense aridity of the hot season greatly reduce the luxuriance of the grasses of the dry meadow, and another important constituent then becomes prominent. This is a series of small xerophytic and very persistent perennials, which are liable to survive both the grazing and aridity because of the development of effective perennating organs. Where overgrazing progresses too far, the dry meadow grasses are nearly or quite exterminated, and a comparatively worthless grass, *Aristida Adscenscionis* L., becomes dominant. It grows up quickly at the beginning of the rainy season, and dies out with the increasing dryness of

the cold season. Dudgeon concludes: "The appearance of this grass marks the last stage of the exploitation of the plant resources by man. When it dies the ground is left bare except for a few scattered half dead tufts of the typical dry meadow grasses, and some of the more persistent rosette weeds".[6]

DESERT, RAVINE, AND ALKALI LANDS.—In the southern and south-western parts of the United Provinces, where both the soil and water-supply are unfavourable for high rural density, the thorn-scrub stage, which occurs in a poorly developed form in the central and eastern parts of the Gangetic plain, reaches a high grade of development. As we move further towards the south-west we approach desert conditions. Here trees form a secondary feature of the vegetation amidst the ubiquitous scrub. In Rajputana the scrub jungle becomes pronounced in its desert characteristics. When we reach the Thar desert the most prominent constituent of the vegetation becomes the scrub jungle, stunted and spiny and ferocious in its aspect. The common trees which flourish in the desert are the *jar, kumbhat, kandi, raneri* and a few other species. In these areas the vegetation has attained a desert climax, while that in the arid areas in the United Provinces, which record a higher rainfall than in many parts of Rajputana, is in a stage of transition, savannah-like, with trees interspersed in the thorn scrub jungle.

In the sandy riverain tracts which are spread along the banks of the Ganges and the Jumma and their tributaries, the scrub jungle is likewise prominent. Coarse grasses, thorny shrubs, and stunted trees here, too, form the main features of the vegetation, and, like the Indus-Valley and Rajputana flora, contain a fair sprinking of African and Arabian elements. The area between the Jumna and the Chambal presents, for the most part, a scene of wild desolation which can hardly be equalled in

(6) See his article in the *Journal of the Indian Botanical Society*, Vol. 1, to which reference has already been made. Compare also his article on the Influence of the Hand of Man on the Distribution of Forest Types in Kumaon Himalayas. For the stages and indicators of over-grazing in the United States, see Clements: *Plant Indicators*, pp. 297-98.

the plains of India. The network of ravines which border both the rivers meets in an inextricable maze, and the tract is mostly bare, or sparsely covered by thorny brushwood or perennial grasses.

We have already referred to wide areas of *usar* land where *reh* is very abundant, and which produces no vegetation. Elsewhere *Sporobolus arabicus* or *pallidus* and *Chloris virgata* are found, which will not thrive excepting on saline soil. *Salvadora persica*, seems to be the only tree that will succeed on the most saline lands, but on the Upper Gangetic plain is rarely met with.

MAN *Versus* VEGETATION.—From the above study it will be evident that man's economic activity in the Gangetic plain has been mainly destructive to the surrounding vegetation. The fertility of the soil and the equable distribution of rainfall have led to an enormous and rapid multiplication of population. This has involved increased economic pressure and consequently a more intensive retrogressive influence of the human factors on vegetation, tending everywhere to throw back succession to an earlier stage and also to modify it, replacing higher types of plant community by lower ones. In the more densely populated parts of the Upper and Central Gangetic plain the vegetation cannot fully develop for lack of protection against the plough, axe, or scythe, or the domesticated animal. The stages of vegetative succession being thus arrested, we have in the more densely populated tracts the dry meadow stage, while in other cases, owing to high rainfall, or less congestion of population, or artificial protection of certain areas, a type of xerophytic vegetation in which thorny bushes and trees abound develops.

PERIODICITY OF RAINFALL.—Another factor that is found to influence the growth of the thorny bush-land jungle is the periodicity of rainfall, occurring at intervals of about eleven years. In the wet cycle the bush-land stage tends to encroach upon the dry meadow stage, and at the same time to establish itself as a more stable plant community. In dry years the vegetation decreases and agriculture becomes more difficult, while grazing by the domestic animals becomes heavier and more indiscri-

minate. The thorn-scrub woody vegetation is more assiduously cut for fuel, while the smaller plants are sought by men for herbs and roots, and pruned by grazing animals to dense oval bushes. Woodlands become shrubless and treeless because of thorough-going destruction; or, again, the cultivated land encroaches upon them and food crops appear, while the grass-lands are shorn of the more useful grasses because of overgrazing. The retrogressive xerophytic type of vegetation, which is now composed mainly of coarser and worthless types of grasses, herbs and shrubs, comes into existence as a result of the inevitable exploitation both by man and cattle during the dry cycle. This diminishes appreciably the fodder value of extensive tracts of land and leads to general agricultural deterioration. It will, therefore, be seen that in the very heart of the Gangetic plain great areas are occupied in drought years by worthless vegetation, and in fact in some tracts the vegetation is entirely destroyed and the ground is left bare and barren.

RECONSTRUCTIVE MEASURES.—There is a great and useful field in the Gangetic plain for the student of plant and human ecology. The indiscriminate destruction or impoverishment of grass-land and forest area has brought to light the problems connected with scientific pasturage and forest management. Various useful measures have been introduced, such as fire protection in forests; replanting of bare tracts so that in the end there may be wood enough for all local needs in the way of fuel, agricultural implements and timber; the reservation of pasture-land as an entity distinct from the cultivated area; the prevention of soil erosion arising from indiscriminate forest destruction; the protection of the sources of rivers which are not perennially fed by the snows; and the scientific exploitation of forests which form the chief source of the income necessary for the accomplishment of these objects. In the plains man no doubt has tended to improve local vegetation by canal or well irrigation; but on the whole the steady expansion of population and the gradual destruction of scrub-land vegetation as well as of the better grass-land through intensive cultivation and

overgrazing are making increasingly difficult the maintenance of a large human and animal population. Scientific rotation of crops, which renovates instead of exhausting the soil; scientific grazing which keeps the grass-land in the most useful stage; protection of vegetative cover to preserve water-supplies and even to permit of human habitation; growth of protective vegetation against the encroachment of sand-dunes or alkali-lands; all these measures must be devised and carried out if the right balance between man and the vegetation definitely in favour of the former is to be maintained. Such measures can be intelligently and profitably applied only after a thorough study of the interplay existing between the various climatic, edaphic, biotic and physiographical factors and the vegetation complex. There hardly exists a region in the world which is so profoundly modified by the direct and indirect interference on the part of man and his flocks and herds as the Gangetic plain. Man's security and well-being are intimately bound up in this congested plain with the discovery of the law that should govern the right adjustment between man's aggression and exploitation and the maintenance and development of the appropriate stages in the vegetation complex. As long as an intensive study of the ecological relation between population and vegetation is neglected, man will reap the fruit of his unholy aggression against the land and trees, his homestead, and be all the poorer for it.

WATER SUPPLY OVERTAKEN.—The stage seems to have been reached when man's exploitation of the vegetable world has reacted so unfavourably upon the conditions of water supply that he can no longer depend upon the progress of irrigation to make vegetation yield his requirements. In tracts south of the Jumna which were seats of ancient Hindu kingdoms, flowing with milk and honey, desert conditions have appeared. Well-irrigation seems to have reached its limit, and fields and pastures have deteriorated. In several canal districts in the West, again, the volume of water that can be supplied by the perennial rivers can hardly be increased. Although the

irrigation canal covers a very large area, the percentage of the gross commanded area irrigated in the United Provinces is very small. A considerable portion of this commanded area is unsuitable for irrigation, either because it is too low or too sandy.[7] The introduction of canal irrigation in the nineteenth century in the Jumna-Ganges Doab led no doubt to some new crops being cultivated, such as sugarcane and wheat on an extensive scale. Maize also was formerly unimportant in Northern India, since there is no trace of its having been brought under assessment by the Mughal revenue officers. Cotton was doubtless grown, but mainly for local consumption. In the case of sugarcane, on the other hand, the increase of aridity in the Jumna-Chambal tract has brought about adverse conditions which have driven out a crop that seemed to have thriven in the past. This is evidenced by the numerous stone cane-crushing mills, which even to-day are encountered here and there among the ravines, embedded in the strata of sand and soil washed down from the rivers. Thus there is a great difference in the character of the agriculture of to-day from that in Mughal times in the Upper Ganges-Jumna districts. Meanwhile the population has enormously increased, especially in the central and eastern parts of the Gangetic plain and in the eastern sub-Himalayan districts. In the time of Akbar the west of the United Provinces was much more cultivated than the east.[8] To-day many of the eastern districts show higher density of population. Within the last three or four centuries an extensive area of forests has been destroyed in the Central and Eastern Gangetic plain and in the Ganges-Gogra Doab. Very probably a large proportion of this tract, where the rainfall exceeds 40 inches, was covered by the monsoon deciduous forests. As the rural density increased and man pressed upon plant resources more and more intensively, the higher and more mesophytic types of forest communities, which had principally supplied his former requirements, had to give place, as a result of continuous slaughter by man and beast

(7) B. D. P. Darley's evidence before the Royal Agricultural Commission.
(8) Mukerjee: Limits and Possibilities of Agriculture in *India Analysed*.

and accompanying change of physiographic conditions, to more xerophytic types of thorn, bush-land and scrub stages. With population continuing to expand, cultivation encroached on the virgin jungle, while both the accompanying increase of cattle population and shrinkage of uncultivated waste area led to more severe and intensive grazing than heretofore. The dry meadow stage now appeared, and to-day it has become the heritage of the intensive agriculturist in the more fertile and congested tracts of the Gangetic plain. Farther away from the more fertile regions of intensive farming—in the north, *e.g.*, in the sub-Himalayan tracts, and in the south, *e.g.*, in Bundelkhand, Baghelkhand and the Vindhyan range, the monsoon deciduous forest has found a safe footing, and still persists, it may be in a modified form in some localities. Soil, rainfall or conditions of water-supply have checked man's advance, and the environmental factors, or even disease, such as malaria or hook-worm, have stemmed the tide of human migration and exploitation. The forces of equilibrium are in some areas definitely in favour of primordial vegetation, and against man. Yet such a forest type might be expected to develop over much of the Gangetic plain, should man's intense pressure upon the habitat become relaxed or released.

FOREST DESTRUCTION AND WATER SUPPLY.—The widespread destruction of forests has also altered hydrographical conditions much to the disadvantage of crop production. It has sometimes led to the drying up of *jhils* and *tals,* which are often the only source of irrigation in the eastern districts. Here the wet meadow stage of vegetation is met with and rice is the dominant crop. In some of these districts, dense forests covered the ground till late in the nineteenth century, but with the expansion of population the percentage of cultivated to cultivable area has gone beyond 80 per cent., and the fields have encroached on the beds of pools and minor streams. There has been of course, an enormous increase within the last few years of well-irrigation; and the drier the year, the greater is the increase in well-construction. Yet

the viscissitudes of rainfall lead to a great shrinkage of the *kharif* area, and to agricultural distress. The water-level, again, is in some areas becoming lower and lower, and this in its turn has already made irrigation and crop production more expensive. The situation is worse in such districts as Muttra, Agra, Etah, and Etawah, where the balance between water-supply and the surrounding vegetation in some cases has been so much impaired that there has been a marked deterioration in agriculture. Here, again, we see another instance of man's short-sighted policy in the past, which has been instrumental in the main in creating conditions that have been adverse to his own welfare. With his thoughtless reclamation of *jhils* and *tals* and destruction of trees and pastures, man finds less and less reward for his labour in the fields. The only hope of re-establishing the climatic and hydrographical balance, which has been upset by centuries of abuse and spendthrift management of his resources, lies in the application of truly scientific principles based on synecology and soil science towards a forward policy of forest and water management.

MALARIA AND DEFICIENT WATER SUPPLY IN THE DELTA.—In a different manner man has upset the balance between vegetation and water-supply in another region in the Ganges plain and brought about agricultural decline. In Central and Western Bengal the streams, which formerly were active distributaries of the Ganges, shrank with the eastward march of this river. But the silting-up of these was promoted also as the result of man's interference, such as that occasioned by river embankments and the shutting out of free river-spill owing to the construction of roads and railways. Various rivers and streams in Northern, Central and Western Bengal have been bridged over and impeded in their flow. The construction of artificial levees built to protect the railway has led in many places to obstructed drainage and water-logging, and impeded flush and flood irrigation in the interior of the country. In the same way roads built without an adequate

number of culverts heighten the danger from floods, and lead to insufficient drainage. The deterioration of the river system has brought about a change in the flora and fauna of the region. Anopheline mosquitoes have increased and there is a rough correspondence between the malaria-stricken area, and the area where the delta-building functions of the rivers have ceased, and water-supply run short. Epidemics of malaria are responsible for a serious decline of population in some districts in the moribund portion of the delta. Where the rivers have strayed from their course and disturbed the internal water and drainage system even in new alluvial formations, malaria has appeared as an inevitable curse of a deltaic tract. Man does not know yet how to deal with this retaliation on the part of outraged Nature. Bentley's table shows that malaria is far more prevalent in the moribund than in the active delta in Bengal.

Bengal districts.	1898	1912	1920
East ..	21·9	40·9	51·9
West ..	17·3	32·3	44·9
Central ..	22·3	23·7	33·5
North ..	9·3	7·5	14·0

The reason is that the larvae of the anopheles cannot flourish in the silty water of the active rivers, whereas they multiply in stagnant pools, drains and streams. In the rainy season stagnant waters carrying a large proportion of weedy sedge make their appearance in the moribund part of the delta, and it is at this season that malaria is chiefly propagated here. The anomaly that malaria is most prevalent in tracts where the amount of surface water has run short and natural inundation greatly reduced in Bengal is thus explained. Paddy, which was originally an aquatic grass, requires a large quantity of water for its successful cultivation. Compared with the advantages of an adequate water-supply, all other advantages, such as selection of seeds, application of manures, or improved tillage, are negligible. With the diminution of water-supply, the *aman* rice which thrives best under inundation has paved the way in the moribund delta for the introduction of a coarse variety of rice, *aus*, which requires much

less water. In many decadent areas the deficiency of water for irrigation, and even for drinking purposes, the prevalence of malaria, and the spread of *aus* paddy co-exist,—all symptomatic of loss of hydrographical balance. The relative dryness will be realised from the fact that the subsoil water-level in Burdwan is 26 feet in the dry season and 9 feet in the rains; whereas in Dacca and Mymensingh it varies from 3 to 5 feet in the dry season and is level with the ground surface during the rainy season.[9] The forest has here gained ground at the expense of the cultivated field, and the area of cultivated land left fallow has also increased. Agriculture has become more difficult owing to deficiency of water-supply, and in many tracts dry and elevated lands are going out of cultivation. In Murshidabad, Nadia, Burdwan, Hooghly and Jessore homesteads have been overrun with jungles, tanks and wells regularly dry up even before summer, rivers have silted up or are choked with vegetation, and the tendency is towards both decrease of population and of area under cultivation. The decrease of fish owing to the deterioration of rivers and neglect of tanks, and the increase of wild hog, leopard, etc., owing to the encroachment of jungle, are also noteworthy changes affecting the balance between man and nature. It is characteristic that this growth of rank vegetation is of a kind that prefers a dry to a damp habitat. Deserted house-sites as well as high river-banks in particular are becoming covered with vegetation. An increase of marsh vegetation would have been an indication of moist soil and climate; trees and shrubs of a dryer region, however, are becoming more prominent. Heavy and indiscriminate grazing by a large cattle population continues and strengthens the tendency towards a gradual reversion to lower forms of vegetation in the dynamic cycle. The supersession of *aman* by *aus* itself represents a degradation of the climatic climax in the Bengal delta. It is true that the ecological succession is mainly connected with the natural history of the deltaic system, but there is no doubt that man's interference with the natural distribution of

(9) Bentley: *Malaria and Agriculture, Bengal*; see also the present writer's *The Changing Face of Bengal.*

rain and flood water by the construction of embankments along the margin of the rivers and for the purposes of roads and railways is also responsible for the loss of balance between vegetative growth and water-supply. Apart from this, the enormous pressure of population constantly tends to thwart the growth of the appropriate stages in the vegetation cycle in the moribund delta. This retrogressive influence on vegetation has been persistently exerted for well-nigh five centuries.

WATER-HYACINTH, AN IMPORTED PEST.—There is another way in which man's lack of foresight has reacted unfavourably by unconsciously altering the conditions of vegetative growth. In the lower delta only the river-banks and the artificial mounds on which habitations are situated escape inundation during the rains. Where not occupied by gardens, these patches of high ground are densely covered with a scrub jungle of semi-spontaneous species, from which rise bamboos, areca, and cocoanut palms with a few later trees, among which the commonest is *Odina Wodier* and the most conspicuous the red cotton tree, *Bombax malabaricum.* In some areas extensive groves of betel-nut palm, *Areca Catechu,* give a forest-clad appearance to the country. The surface of the marshes either shows huge stretches of inundated rice or is covered by matted floating islets of sedges and grasses and various waterlilies, the most conspicuous of which is the makana (*Euryale ferox*).[10] Now in a tract where marsh plants and weeds are found in great variety and exuberance an irresponsible Englishman cultivated the water-hyacinth for the sake of its flower in his pond in Narayanganj, and the weed spread when the waters of the great rivers overflowed during the rains. Great storm-waves are recurrent, and after each storm-wave the weed goes to every *khal* and streamlet, making both agriculture and inland traffic more and more difficult. In the districts of Dacca, Faridpur, and Mymensingh, the eradication of this pest adds greatly to the labour of cultivation, and in spite of all his care a cultivator may lose an entire field of

(10) *Imperial Gazetteer of India, Eastern Bengal and Assam.*

paddy through a great mass of the weed being carried by the current from a neighbour's field or a common waterway to his land. In fact, in some areas, where the pest has grown thickly, cultivation has become impossible, and the peasant has given up fighting the weed in despair. Communications by boat during the rains are also being blocked through the water-courses becoming choked with water-hyacinth.[11] The total area covered by the pest in Bengal now comes to 4,269 square miles, more than half of which represents cultivated areas; while it has also spread to Assam, and to Bihar and Orissa. Here we have an outstanding example showing how even a single individual in the human complex can consciously or unconsciously be instrumental in upsetting the long-established equilibrium between the human and plant communities of a region. Man's health and welfare are inextricably linked with the conditions of the flora and fauna of the region in which he lives by chains of actions and interactions which very often he is slow to comprehend. In this case, by deliberate toleration of a plant pest, he has let loose forces which have violently disturbed the biotic balance over an extensive area in Bengal which he now finds most difficult to control.

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(11) S. G. Hart's letter, *Final Settlement Report, Dacca.*

CHAPTER VII.

HUMAN INTERFERENCE WITH ANIMAL ECONOMY.

CHANGES IN FORESTS AND FOREST LIFE IN INDIA.—Across the bare, treeless Upper and Middle Ganges plain there once extended a dense forest, dry, stunted and thory towards the south and west, and moist and luxuriant in the sub-Himalayan tract and the east. Such a deciduous forest extended in historic times from the submontane tracts of the Himalayas much farther into the United Provinces, Bihar and Bengal than is now the case. Only three centuries back the frontier of settled cultivation hardly extended beyond a line drawn north of Bareilly, Gorakhpur and Muzaffarpur in the Upper and Middle Ganges plain. The prevalence of forest land meant necessarily the presence of large number of both herbivorous and carnivorous animals; herds of elephants, wild buffaloes, and rhinoceroses were common, not only in the hilly country south of the Ganges and the Jumna, but also in the swamps and wilds of the entire tract from Bijnor to Muzaffarpur. Lions and tigers were frequently hunted in the uncultivated wastes between Agra and Delhi, while large portions of the Central plain where there were only patches of settlement were sometimes visited by these animals. Finch, writing in the 16th century, mentioned that the road from Jaunpur to Allahabad lay through a continuous forest while the Akbarhnamah records the fact that forests were traversed and various strange beasts seen during a march along the southern bank of the Gogra in what is now the congested district of Azamgarh.[1] Along the Ganges from Allahabad to Monghyr, both population and culti-

(1) Moreland: India at the death of Akbar, p. 22.

vation expanded four or five fold within three centuries. The Ganges-Jumna doab, *i.e.,* district between the rivers was, however, fully occupied and densely peopled for well-nigh four or five centuries though both cultivation and population were sparser in the doab from Agra towards the east. In the north, the *Terai,* a region of marsh and fen, overgrown with jungle, extended much nearer the Ganges than is now the case. Here live the *Tharus, Bhoksas* and other cognate tribes, essentially marsh dwellers, and more or less immune from the jungle fever, who are pushing the frontier of cultivation to the foot of the hills to which the tiger and the elephant, the rhinoceros and the wild buffalo, the antelope and the swamp deer retreat. Col. Sleeman, touring through Oudh in 1850 found the forest beginning only a few miles to the north of Bahraich and passed through a belt of jungle between Poknapur, Gokaran Nath and Kurrunpur Mirtaha which runs from the great forest to the north, a long way down south-east into the Khairabad district. The forest belt has now receded much further. According to Sleeman's estimate, the Terai forest covered four to five thousand square miles, the whole Oudh territory including this forest containing 23,739 square miles. He also gives a list of twenty-four belts of jungle, beyond the Terai forest covering a space of 886 square miles at a rough computation, where the landholders found shooting and fishing and built forts for the security of themselves and their families and the oppression of the people on the neighbouring estates. These areas have now gradually been brought under the plough. Where there were fens and morasses, coarse grasses and thickets of reeds, extensive rice fields now stretch and hamlets cluster driving farther and farther the denizens of the aboriginal forest to the ever thinning frontier between the low and the upper country. The Ganges-Gogra doab had been mostly forested and waste area until the beginning of the last century. Yet this tract in ancient times contained the flourishing cities of Kapilavastu, Devidaha, Kusinagara and Sravasti, visited by the Chinese pilgrims, who found some of them thriving till

the fourth century A.D. They, however, found signs of deterioration in the seventh century. This area probably had reverted to the original forest owing to the shifting of the river Tapti and an epidemic of fever similar to that which later wrecked the civilisation of Gaur and Pandua in Northern Bengal, and it could not be penetrated by the Muhammadan conqueror but became the home of the aboriginal tribes and castes, and of the Rajput chieftains displaced from the plain. It is here that the destruction of forests and spread of cultivation were most rapid, superseding the forest fauna during British times.

FORESTS AND FOREST FAUNA IN TRANSITION.—Animal and plant communities are intimately bound up together in ecological succession. Over much of the semi-arid Upper Ganges plain, the intense pressure of human and animal factors on vegetation has thrown back vegetative succession to an earlier stage. Thus we have now the dry meadow stage in the Upper plain, while in the Central plain, where there is higher rainfall or less biotic pressure, the vegetation is xerophytic, thorny bushes and trees predominating. The original deciduous forest which extended over the entire Ganges plain has been completely transformed by the intensive retrogressive influences of man, cattle, sheep and goat. This vegetative metamorphosis has led also to a vast number of changes among the animals, gradual or catastrophic, as to which accurate information is not available.

With the enormous increase of human population and expansion of cultivation throughout every part of the plain, forests and meadows have been superseded by cultivated fields, while there has been also an enormous multiplication of cattle, sheep and goats. Due to the human factor the domesticated livestock have multiplied enormously, and it is these which have become the controlling factor in the change from forest to a savanna-like type of vegetation throughout the densely populated plain, banishing the original forest fauna from its natural habitat, curtailing its range and gradually driving its members to extinction. The lack of large open spaces among the

shrubs and thickets which gradually superseded the aboriginal forest, made it difficult in particular for the large predaceous animals to pursue their prey; hence these gradually dispersed or declined rapidly in numbers.

Man also has deliberately destroyed these animals for his own safety. In India there are systematic measures for the destruction of carnivores which have taken the form of rewards on the production of the carcass. A special staff of hunters for the destruction of tigers, leopards and wolves was maintained in some districts, leading to much reduced numbers, if not extinction, of these carnivores; while some castes such as the *Baheliyas*, *Aheriyas, Chirimars* etc., even now obtain a livelihood by trapping game birds. The decrease of leopards, panthers, deer, and wild pigs, has also corresponded with the increase in the export of skins and hides, which find a profitable market. The Government of India maintains a department for the capture of wild elephants, which yields not a small income, and has contributed not a little towards the diminution of herds of elephants in the whole of the Sub-Himalayan tract from the Punjab to Assam. Among the larger carnivores the lion and the tiger, which were found on the Ganges, and the Jumna till the middle of the last century, have entirely disappeared.

Now, such carnivores like the lion, the tiger, the leopard or the wolf play an important role in the economy of Nature. It is these predatory animals which keep down the numbers of such herbivorous wild mammals like the deer, antelope, pig or rabbit which have been fairly numerous in the region. With the destruction of their usual enemies, the ecologic balance of numbers of these animals is upset, and by multiplication these usurp more than their due place in the general harmony of nature. Further, India maintains excessive numbers of useless cattle which encroach upon the scant fodder of the useful live-stock. Where the tiger is a cattle-killer, he chiefly preys upon the which Hindu religious sentiment preserves to the detriment of better animals. The result is that these decrepit stragglers of the herd, old worn-out cows and bullocks

animals meet with a speedy end under the tiger's claws instead of being pecked to death by vultures as occasionally happens. This is why tigers in incredible numbers still exist in many parts of Nepal, cheek by jowl with the large herds of cattle on which they prey in default of the ungulata, which in that country have been mercilessly slaughtered for butcher's meat.[2] Throughout the crowded areas of the Ganges plain the extermination of the carnivores and the ungulata has, however, gone almost hand in hand. The decrease in carnivores could permit the marked increase in the ungulata, especially deer, which must have had a considerable effect on the vegetation of the prairie and herbage and foliage available for herbivores and rodents in general, especially in years of bad rainfall. But the destruction of the forest and persecution by man caused ultimately the decline of most of the ungulata. This has enormously increased the food-supply of many insects, birds and such small mammals as squirrels, rabbits and rats.

The Indian bison, the wild pig, the wild ass (*Jhorkar*) and the black buck disappeared about the same time from the prairies whilst the country was becoming colonised. In the early eighties wild pig were fairly numerous and aggressive in some districts of the Central plain, and used to attack men who were tending their fields.[3] The *nilgai* (Portax pictus) also existed in large numbers, roaming in herds of 20 or 30, but the peasants fast killed them off. To the south of the Jumna in the wild raviny tract, and sometimes on the khadirs of both the Ganges and the Jumna and in the long strip of the Terai, covered with jungle, to the north of Kheri, Bahraich, Gonda and Gorakhpur the carnivores are now mostly to be found, having been driven there as colonisation has progressed. Tigers, leopards, hyenas, bears and wild dogs are met with and occasionally wild elephants and buffaloes in the swamps and grass-lands of the Terai. Irwin, writing about Oudh

(2) W. Ameer Ali: The Fauna of India, Asiatic Review, 1930, p. 102.

(3) See Statistical Account of the N.W.P. Watehpur District.

only fifty years ago observes: "The wild buffalo used to be not uncommon here but is now extinct. Sambhar and the barking and four-horned deer are rare, antelope and spotted deer are fairly plentiful, nilgai and pig super-abundant and extremely mischievous to crops. The gond or swamp deer, a species of water-sambhar and the hog-deer or parha are to be found among the vast sheets of high grass that cover the low ground along the Girwa and Koriala rivers." Gwalior became for many years the shelter of many larger mammals that were driven out of the inhabited plains. Thus lions, tigers, wild buffaloes, and wild asses were safe in the forests of Gwalior until recently. The tigers, however, multiplied to such an extent that they drove the lions to the outskirts of the villages, and the inhabitants hunted them down. By the eighties the lion almost disappeared. Kathiawar and Baroda now harbour and protect the last Indian lions. The last bison in Gwalior, a herd of thirty, was killed in 1917. The wild ass was hunted down earlier and isolated herds survive in India only in Bikanir, Bhawalpur and Cutch.

The Government Reserved Forests similarly have been the last refuge of much of the fauna which could live and thrive there without let or hindrance to man if he is not considerate. Thus in the forests of Gonda, North Oudh, are found tiger, bear, leopard, hyena, wild dog, wild boar and three kinds of deer, with two of antelope. This was varied in 1924 by the visit of a stray rhinoceros. As shown by place names, the wild elephant has disappeared from this area but recently. But even in the Reserved Forests the tiger is fast diminishing in numbers, while the ungulata have been almost exterminated. Beats which one knew well to contain many mature sambhar stags as well as brockets now contain not a single one, and barely a doe. Axis or spotted deer have been estimated to be 75 per cent. less than in 1912.[4] All this has been the result of man's wanton destruction of herbivores and carnivores alike. With the extermination of herbi-

(4) W. Ameer Ali, The Fauna of India, Asiatic Review, 1930.

vores in these magnificent forests the carnivores have found their food scarcer, and this has speeded up their extinction. The main reason why the tiger turns into a cattle-killer and a man-eater, which is rare, is the diminution of its natural food-supply. "Man eating," rightly observes Ameer Ali "is either the result of bad upbringing by a tigress hard put to it to provide for her cubs or the result of the extermination of game by man, leaving no other source of food-supply than cattle or their guardians." Thus there is a vicious circle established, no pig, deer or antelope, then no tiger or only tiger which is driven to man and cattle killing, and is a menace to the human settlement.

In the Jumna tract leopards abound and sometimes tigers put in an appearance, and these occasionally intrude beyond. In these localities hyenas, wolves and wild cats are also common, but as a rule these do not commit depredations in human settlements. In raviny or broken ground, and often where the country is undulating, among the herbivores we have the ravine gazelle or chinkara, black buck and *nilgai* which roam sometimes in small herds. The wild pig also has now its home chiefly in the *khadirs* of the Ganges and Jumna and in the lowlands of the rivers. He is also found in abundance in Rampur State where he had been long the chief obstacle to the progress of cultivation. Near about villages throughout the plain he is found along with bucks and *nilgais* in *dhak* or thorny jungle which may still persist as vestiges of the original forest formation against the encroachment of the axe and the plough. The survival of only a few communities of the earlier deciduous forest has enabled a great number of animals to hang on also, and these, of course, cannot be separated in their inter-relations with the new-comers.[5]

LOCAL VARIATION OF ANIMALS.—It is also remarkable that, though the animals belong to the same species, yet they exhibit different characteristics in the fens and swamps of the Terai and in the Vindhyan and Kaimur

(5) For an instance from England see Elton, Animal Ecology, p. 26.

ranges and ravine tracts south of the Jumna and the Ganges. As a general rule, animals in the forests have a tendency to be large, strong and muscular, compared to those of the open plains or waterless hills. Thus the wild pig of the southern hills and khadirs of the rivers is leaner and gaunter than the heavy beast of the Terai. It appears that there is a general relation between the sizes of animals and the water resources of their habitat; some species grow larger where water is abundant and some large animals are entirely absent where it is not. The season of failing water may also directly influence the life cycles of animals.[6] The black buck that one meets with in the Central Indian hills or riverine tracts seldom grows long horns like those of the same species in the grass-lands of Agra and Muttra. Similarly the hill tiger is a different animal from that of the Terai. Thus Crooke observes: "He is a shorter, fiercer and more active brute, trained to greater endurance, his muscles toughened by the long range of country he must cover nightly in search of prey. The leopard, too, from his environment, is distinguishable from the Bengal species. In the damp Himalayan forests he is darker and redder in colour, and has larger spots than in the Central Indian hills. Thus his colour resembles the background against which he is seen. Some naturalists have gone so far as to separate the two varieties, but the best authorities are disposed to consider them identical in species—the difference being due to the fact that one is the denizen of the thick, marshy swamp or damp jungle, the other inhabiting the rock caves or the bamboo clumps and stunted thickets of the waterless hills."

ANIMAL MIGRATION.—In the Upper Ganges plain we sometimes meet with large herds of black buck which migrate from the desert area and upland plateau during years of draught, and many are the contrivances to which the peasants resort for the protection of their wheat and barley from the marauding herds. Such herds are, however, hardly to be met with in an eastern district, such as Benares or Ballia. Similarly it has been found that

(6) Pearse: Animal Ecology, p 230.

the common *bandar* or Rhesus monkey and the *hanuman* monkey of India migrate in parties (formed of a mixture of the two species) from the plains to the hills of Nepal in the hot season and return in the cold season, carrying their young with them.[7] Wolves and jungle dogs are met with here and there in the plain, especially in the districts bordering the Terai, and the Southern ranges, though these were much more common a few decades ago. Thus Sleeman, writing in 1850, observes: "Wolves are numerous in the neighbourhood of Sultanpur, and, indeed, all along the banks of the Goomtee (Gumti) river, among the ravines that intersect them and a great many children are carried off by them from towns, villages and camps."

WATER-SUPPLY AND ANIMAL LIFE.—Throughout the region it is the water-supply which is the prime controlling factor in the distribution of many wild birds and mammals. The occurrence of leopards, antelopes, pigs, monkeys, etc., is determined in the dry season by the proximity of streams, and accordingly the khadirs of the rivers, which offer a suitable forest-cover, shelter these animals. In the case of rooting and digging animals, such as moles and porcupines, the softness of the ground, which in turn depends on the water-supply, governs their distribution. A very close association between vegetative and faunal areas cannot be established. Thus the plains harbour certain animals that properly belong to the prairies, and *vice versa.* The plain, prairie, or steppe has each certain animals that are distinctive, but few species are wholly confined to one plant association.

LIFE OF THE STEPPE AND PLAIN.—One of the most characteristic animals of the steppe is the uromastix, a lizard with spikes in his tail which feeds on grass and lives in a hole which he digs himself of no great depth. Lizards are being destroyed in large numbers on account of the value of the skins. The extermination of lizards has led to so great an increase of snakes that in one district recently a law had to be passed making such slaughter illegal. The gecko or wall lizard is another familiar reptile of the steppe.

(7) See Elton's Animal Ecology, pp. 152-153.

In the group of active burrowers also fall certain snakes and nearly all the small rodents.

On the steppes the dominant animals are, however, insects, like collembolans, termites, dragon-flies, locusts, beetles and hymenopterans and various species of spiders being abundant. Large flights of locusts visit every year the dry districts of the plain, devouring every green thing in their path. Morse stressed the fact that the best flyers among locusts are found in open fields, where ample spaces such as the Punjab and Ganges Valleys make dispersal and escape from enemies easy, especially through the aid of winds. These swarms of locusts periodically migrate from the arid regions of Western Asia to the nearest and prosperous plains of Northern India where they have become a serious menace to agriculture. Scientific campaigns for their extermination have started, but the poorer agriculturist classes have their own way of solving the problem by using them as their food. As contrasted with locusts and grass-hoppers, (Uvarov found that locusts have evolved from sedentary grass-hoppers) many of the insects that live in bunch grasses are typically sedentary, but the "inter-stitial" animals, which frequent the interstices between vegetation, are usually swift and predaceous. Many of the larger herbivores and rodents in general are swift, and the same is true of certain of the carnivores that pursue them.[8]

Of birds the house-sparrow is common enough to be a nuisance. The small sand-grouse is also numerous in the dry areas of the plain. Large flocks of small birds such as the "samga" and the blue-coated *kunj* periodically visit the dry areas in the cold weather, and do great damage to the crops. Other common birds are the maina, the green parrot, the dove, the blue pigeon, the crow and the black raven. The black partridge is found chiefly on the rivers, while the quail is similarly limited by water-supply to areas of scrub beside rivers.

(8) Pearse: See Animal Ecology, p. 265.

ADAPTABILITY IN TIMES OF SCARCITY.—In the dry areas among the ungulates the camel is more frequently met with than in the eastern districts, drawing carts and sometimes ploughs, lifting water for irrigation and serving generally as a beast of burden. Horses are far less common. Both camels and cattle show extraordinary adaptation as regards the use of plants and grasses as fodder during times of scarcity. The camels eat almost any kind of plant and being able to live on food that does not support horned cattle, are therefore less liable to die off in great numbers in times of scarcity. Even man shows wonderful adaptability in this respect when famine compels. The following rough list[9] by no means a full one, illustrates famine food and fodder:—

MAN.	CATTLE.	CAMEL.
1. Berries of Zizyphus nummularia (Jharberi).	Leaves of Zizyphus nummularia.	Capparis; Zixyphus; Zygopbeyllum Agriophylum
2. Pods of Prosopis spicigera (*Jandi* or *khajri*).	Pods, leaves and twigs of Acacia arabica (Babul).	
3. Fruit of Capparis aphylla (*karil*) ground and mixed with flour.	Kochia indica, (*Bui*).	
4. Fruit of Salvadora oleoides (Van or Jal).	Alhagi camelorum (*Jawasa*).	
5. Leaves of Suaeda maritima (hana).		
6. Leaves of Cicer arietenum cooked with *Jowar* flour.		
7. Seeds of Cenchrus echinatus (*Bhurt* grass).	Salsola foetida (Sajji).	
8. Tubers of Cyperus rotundus.		

REDUCED FAUNA OF THE PLAIN.—It is thus, when the scarcity of rainfall brings the human and cattle population to the verge of starvation, that every possible kind of grain, fruit, leaf or seed is utilised by man, and the cattle resort to worthless grasses, thorny shrubs or bitter leaves and twigs. During most severe famines even the bark of mango or blackberry is of great value to the poor. While the constant browsing by domestic cattle, sheep, and goats has led to the reversion of the vegetation to an earlier stage and thereby to important changes in the distribution of the larger predaceous animals, the domestic beasts themselves have to graze on every kind of shrub and herb,

(9) For a full list see Gammie's Note On Plants Used For Food During Famines In Bombay.

thorny, bitter, or nauseating in taste or smell, during lean years. The dry climate and general absence of trees and water, as well as periodical deficiency of rainfall, have made the larger mammals comparatively scarce over much of the Ganges plain, western and central; while cattle famines are more recurrent now due to the absence of pasture grounds and gradual destruction of forests and the supercession of sparse vegetation on the river banks by useless grasses due to over-grazing. Two inter-related and co-acting factors have thus been at work in driving away the larger mammals from this area. The destruction of forest shelter by human agency and of vegetation by domestic live stock rendered the lives of the larger mammals insecure and precarious. Coupled with this the gradual reclamation or drying up of the swamps, the diminution of rainfall and the marked decline of the water-table increased the unsuitability of the area for their breeding places, forage places and shelter. The seral stages of disappearance would be: (1) the rhinoceros, the wild buffalo and the pig which require the largest supply of water, as in fens and marshes, for their breeding sites were the first to become extinct; (2) the turn came next of the elephants, lions and tigers; and, (3) such large mammals as the *nilgai*, deer, and antelope have been the last to disappear; these are still present in small numbers here and there. In the normal course of expansion of population and cultivation, it has taken less than three centuries—an exceedingly short period in the history of animal life for the disappearance or extinction of the larger mammals in the Ganges Valley.

There has, of course, been desiccation. We cannot otherwise explain how the Emperor Babar could have hunted the rhinoceros in the Jumna tract or found the capture of wild elephants a profession among the people of Karrah in modern Allahabad District or the Emperor Akbar could have found tigers in abundance in the neighbourhood of Mathura, now one of the driest tracts in the Province. That the rhinoceros was a common animal in the Ganges plain in ancient India is suggested by the

comparison of the Buddhist monk with a rhinoceros roaming alone in the forest and Asoka's injunction in his pillar edicts against the use of rhinoceros flesh, which used to be eaten even by the Brahmins and was believed to have medicinal properties according to Charaka and Susruta. Megasthenes (300 B.C.), also gives a curious description of the rhinoceros as a one-horned deer, which is also the classical description of Buddhagosha. The animal was found in considerable herds on the banks of the Sarju and the jungles of Chunar in Moghul times. In fact rhinoceros horn and hide were important articles of trade in Oudh province. The herds of rhinoceroses seemed to have already disappeared in this region by the sixteenth century. The last traces of the rhinoceros were reported in the Sunderbuns in Bengal about 1887. The year 1885 or so saw their disappearance from the Sonthal Parganas. The Indian rhinoceros must be considered as doomed to perish, and is already a rare beast. It is found now only in the heavy grass jungle in the river beds of the Nepal Terai, North Bengal, Assam, the Chittagong hinterland, Burma and where Burma runs into Malaya. The animal frequents regular paths which take the form of 'tunnels in the jungle', and has a poor vision, and so has been an easy victim of wanton aggression, and rapidly disappeared within the last few decades. Only a few heads are said to remain, and recently the Bengal Rhinoceros Preservation Act has been passed to save a few animals that exist in "a certain area in the Jalpaiguri Jungles". Babar described tiger, rhinoceros, wild elephant and buffalo, and Akbar experienced herds of wild elephants under the walls of Chunar, and tiger or lion hunts were organised along the Jumna bank by the later Mughal Emperors. Tigers, lions, bears, leopards and wild buffaloes were killed in large numbers by Jahangir in his hunting expeditions in the region between Agra and Delhi, and in Ajmir and Malwa. Bernier stated that the country about Agra and Delhi, and along the upper course of the Jumna, had extensive waste tracts abounding in wild beasts, and that, among other animals, the lion was frequently hunted and slain by the

rulers of Delhi. According to the Persian work, *Khula-satul-Tawarikh* (1695) we learn that wild buffaloes were plentiful in Oudh towards the end of the 17th century. It is described that when the plains and deserts became covered with water at the beginning of the dry season owing to the river being in flood, the wild beasts came to the human habitations and men had the pleasure of hunting many kinds of game. By 1869 Oudh had a population density of 474 to the square mile.[10] Within a century and half 77 per cent. of the whole area in Oudh came under cultivation, driving both the herbivorous and predaceous animals to the jungles of the Terai. According to the same authority, in Tirhut which is now one of the most densely populated areas in the Ganges Valley, tigers were met with; and in the rainy season, owing to the excess of water, the deer, the elk and the tiger came down together to inhabited places, and men had the pleasure of hunting them.[11] As late as the beginning of the 19th century Hamilton referred to lions existing in vast numbers in the Saharanpur districts, and Royle also spoke of the animals occurring to the west of the Jumna, especially on the edge of the desert near Hansi. Through the wide wastes and forests in the sub-Himalaya region, rhinoceroses, wild buffaloes and elephants used to roam till the middle of the last century. Wild elephants were occasionally seen in the swamps of Bashta in the Bijnor district at the beginning of the last century. Buchanan (1812-13) stated that in Gorakhpur the wild elephants frequented chiefly the forests, but at night came on the open plains and did great damage to the crops. "The rhinoceros" he adds, "is not so numerous as the elephant but the wild buffalo is said to be very numerous and to be seen in herds of 2 to 300".[12] The last specimen of wild buffalo was obtained in Gorakhpur in 1896 and the rhinoceros disappeared a few decades ago. Tigers, bears and leopards have become almost extinct, though these were abundant in Buchanan's time. As late as 1873, however,

(10) Irwin: *The Garden of India*, p. 27.

(11) Sarkar: India of Aurangzeb.

(12) Martin: Eastern India, Vol. III, p. 503.

a tiger was shot in Gorakhpur city itself. In the Central and Western districts tigers disappeared much earlier. In 1803 tigers were shot in the wild country surrounding the ruins of Kanauj, but by the eighties were nowhere to be seen in this tract. For many years it was believed that the last lion in Central India was shot in Gwalior at Guna in 1873. Nevertheless a few lions managed to survive in the Sheopur jungles, chiefly on account of the protection afforded by the Gwalior State since 1875. In 1930 the last isolated numbers were shot in several widely apart places, the ultimate survivor near Jhansi in the United Provinces.[13]

The wolf seems now to be the only representative of the larger carnivores which can be called a habitant of the densely-crowded plain: he does some damage to calves and goats, but seldom molests human beings. In some districts the expansion of cultivation and destruction of jungles have now made even the wolf very scarce. The destruction of snakes is inevitable. Deaths from bites of poisonous snakes are not few, but all snakes are not poisonous, and indiscriminate destruction of these would mean a multiplication of mice, rats, squirrels, etc., which are great pests. Over a large expanse of the plains wild pig, *nilgai,* and black buck, which seemed to have existed here and there in sufficient numbers at the last settlements to attract attention, have also wholly disappeared or have been reduced to a few isolated heads or small herds. Even the common birds are not numerous. The destruction of forests has changed the entire face of the country and deprived many birds of their old homes. The reclamation of marshes had led to the disappearance of marsh birds, while the extension of cultivation has meant a great loss of shelter for nests and restricted breeding conditions. Thompson, in his *Biology of Birds* commenting on the destruction of birds, remarks: "The continuance of the system of Animate Nature depends in part on the check that birds keep on injurious insects and on small mammals like voles." The white herons which formerly throve in

(13) Edward Thompson: Rare Beasts, The Statesman, June 2, 1932.

the rice-fields of the Ganges valley have been greatly reduced in numbers owing to indiscriminate destruction by man. Their presence, however, is very beneficial to the crops because of the check that they maintain on the multiplication of insects in lowland or marsh. A few birds are injurious to the interests of the farmer and the gardener, but the great majority are beneficial. Some destroy snakes, others rats, others mosquitoes, others check the increase of voles and sparrows, plant-lice and scale insects, yet others check various injurious insects that destroy man's permanent products. Thus the destruction of birds is on the whole very unfavourable to agriculture. Since certain trees have disappeared, the birds which are more or less dependent upon them are no longer to be found, while the herbivorous animals which are attached to some plant, either for food or for breeding purposes, or for both, have also become scarce with the change in vegetative succession. Some have entirely disappeared, as we have already stated, as a result of the lowering of the water-level and increase of aridity. Thus the rooting and digging animals in particular are susceptible to a change in the conditions of humidity and water-supply. Reference may be made here to the periodical migration of herds of antelopes from the sandy tracts and uplands of the West to the less arid grass-lands of the upper plain during years of unfavourable rainfall. It is also probable that some antelopes and gazelles do not drink water, but derive their water-supply from the desert herbage and possibly from dew.[14] Their inroads are a serious matter to the peasant.

During the cold weather, too, the rivers and *jhils* are the haunts of enormous numbers of snipe, wild goose duck, and teal of many varieties, which are all migratory. The *jhils* of the Terai districts, and the riparian tracts in the east are richest in bird life, and enormous numbers of birds concentrate in favourable areas in the hot season. When the *jhils* are reclaimed for cultivation, or emptied by the process of irrigation, birds are found in much

(14) See Buxton: Animal Life in Deserts; p. 89.

smaller flocks than before. Not merely migratory birds but also non-migratory game birds, such as the common spot-bill or comb duck, have greatly diminished in numbers in the Plain.

SUBSTITUTION OF ANIMALS—PROFIT AND LOSS.—The problem of securing a nice adjustment between the interests of agriculture and the preservation of the larger mammals and birds in India is a complex one. The plains of India exhibit larger aggregations of human communities as well as more interesting and varied animal communities than probably anywhere in the world. "The fauna of India is so noteworthy," observes Thompson, "because Malayan and African elements mingle, Central India being the actual meeting place." The problem can be solved only by a balanced and judicious policy of vegetable and animal protection based on intensive ecological reconnaissance of the influence of plant and animal life on man and *vice versa*. With regard to such herbivores as the *nilgai*, deer, antelope, wild buffalo and pig, whose numbers have been enormously reduced in many areas, it is easy to keep their numbers at a proper level by a more cautious distribution of gun-licenses or by the discrimination between arm licenses and game-licenses. Sanctuaries may also be established in certain areas in the plain, and here as well as in the Government Reserved Forests the capture and killing of various species of the larger mammals and birds may be strictly restricted by regulations and ordinances.[15] The interest of crop-protection, sportsmanship and the game have been co-ordinated both in the Soudan and in Kenya, where the larger mammals are far more numerous than in India. There is no doubt than in India where the destruction of the fauna has proceeded very rapidly such a policy is urgently called for. In the United States of America a very strict system of control has been introduced. Without a limit to the amount of game-animals and birds which may be shot by a gun during a certain period and a strong public opinion to enforce such ordinances, the complete

(15) According to Kautilya, (800 B C.), whoever killed an elephant was put to death in Maurya India.

destruction of birds and animals which is now being carried on in India cannot be effectively checked. The purpose of wild game preservation and animal and bird sanctuary laws should be not to benefit sport but to fill the gap in the garment of Nature, based on a scientific consideration of the food and other inter-relations between different species of animals and of man in the region. Man's destruction of the natural vegetation of the plain and his extermination of wild birds and animals has, indeed, upset the harmony of nature. Other species that are injurious to man and his products have increased above their normal numbers as the result of a break away from control by their natural enemies. Man has thus set in motion actions and interactions which he cannot control, and which have proved detrimental to the entire living complex including himself. Man's knowledge of the relative importance and rates of increase of the different parts of animate nature in the setting of the natural environment can alone assure a scientific control and husbandry of the wild life. The ecologic balance and rhythm of growth for all living communities, wild as well as domesticated, which in fact represent the very essence of the region's life-process, must be restored for it is here where lies the permanent security of man himself.

Certain animals, however, have rapidly multiplied as a result of man's action with expansion of population and human settlement. Many animals have followed man's trail as he has extended the frontier of cultivation. Many animals he has imported, others have lived upon his food and waste products. Some of these are actually encouraged in their multiplication, many are tolerated, while others live and multiply dangerously at his expense. Ritchie, studying animal succession in Scotland, found that more species of animals have been introduced than have been exterminated since man entered into the Scottish kingdom. Thomson points out that this seems at first very satisfactory, but is not the whole truth; for, while the fauna has actually gained in numerical strength, it has fallen off in what we might call faunistic value or standard. The visible has been replaced by the invisible,

the giants by the pygmies. "We have in effect lost more than we have gained, for how can the increase of rabbits and sparrows, and earth-worms and caterpillars and the addition of millions of rats and cockroaches and crickets and bugs ever take the place of these fine creatures around the memories of which the glamour of Scotland's past still plays—the reindeer and the elk, the wolf, the brown bear, the lynx and the bear, the bustard, the crane, the bittern and many other, lost or disappearing".[16] In the Ganges valley a similar substitution of fauna has taken place, and a far greater decline of the faunistic standard, since man's influence on the world of organic nature has persisted here not for decades but for centuries. In India it is really a case of the giants being superseded by the pygmies—the wild elephant, the rhinoceros and the buffalo, the lion, the tiger and the wild bear, the black buck, the *nilgai* and the wild ass, the mongoose, the fox and the wild cat, the peacock, the weaver-bird and the great bustard, the florican, the quail, and the partridge either have become extinct or are fast disappearing; and what have multiplied are the mosquitoes and sand-flies, ticks and mites, which make life a burden, the caterpillars, moths, locusts, ants, beetles and insects of all sorts which attack the crops; the sparrows and the *saragas*, the squirrels and the rabbits, the mice and the rats, which do great damage to the crops and seem to be yearly increasing in numbers and in their ravages, not to mention the wasps, scorpions, spiders, fleas and bugs. Rabbits, rats and mice are a plague in many districts of the United Provinces, and in some years when weather conditions are favourable, they become a serious menace to the farmer. It is calculated that a pair of adult rats is capable of multiplying to two lakhs at the end of three years, while each full grown rat can consume about 2 ounces of dry grain a day and cause much greater damage to the growing crops in the field.

In one direction man has greatly improved both the number and quality of animals. He has directly encouraged the multiplication of cattle, buffaloes, camels, goats

(16) Ritchie: *Animal Life in Scotland*.

and sheep, and enriched their quality by importing new breeds from other regions. But even here excessive numbers are proving unfavourable to the species. The livestock of the Ganges plain has enormously multiplied as a result of agricultural expansion. The reclamation of wastes has made the problem of cattle food acute, since there are few localities where fodder is especially grown. The cattle, increasing in numbers beyond the forage resources of the neighbourhood, have rapidly changed the character of vegetation; noxious weeds survive, and nutritious plants are gradually exterminated by close and persistent browsing. Thus are the village cattle themselves not only deprived and starved, but also the natural fertility and humidity of the soil are so dangerously lowered that any untoward climatic disturbance too frequently means famine, which takes its ruinous toll both from man and beast.[17] Yet agriculture in small holdings is economically impossible if the fodder of the working animals must be bought; and the holding must provide it, either in the shape of fodder crops or of the bye-products of other crops, the straw and stalks (principally those of the millets) which form the bulk of the fodder supply. The result is a close relation between the size of a holding, the class of crops grown, and the number and quality of the cattle employed; and it is this which accounts for the violent contrasts between the cattle in the different tracts, from the costly and powerful animals on the large holdings in the western districts, where fodder crops are freely grown, to the miserable and half-starved beasts in the rice tracts of the east.[18] During famine years whether in the western or in the eastern districts cattle die by thousands. In 1897 something like 75 per cent. of the cattle perished in certain districts of the Ganges plain. Veneration for the cow has had a positive effect in protecting the cattle, and large numbers of useless animals are now being maintained even in crowded areas of the plain leading to

(17) Wats: The Commercial Products of India, p. 741.

(18) Report of the Provincial Banking Enquiry Committee, U.P., p. 239. In the Gangetic plain the number of cattle per 100 acres of sown area increases from about 90 in the United Provinces and Bihar to 108 in Bengal. The corresponding figures are 15 for China and 6 for Japan. See the writer's Human and Bovine Population Pressure in India, *Indian Journal of Economics*, 1936.

chronic shortage of fodder and deterioration of breed. The small cultivator has his own way of meeting the fodder famine; he sells his cattle in April as soon as he can spare them, and buys new ones in June, thus avoiding the expense of feeding them at the time when fodder and grazing is shortest. Further in the western districts, as in the Punjab, the cultivator prefers buffaloes rather than cattle, for the former are heavier milk-yielders and can be more easily disposed of even for slaughter than the latter. Buffalo-rearing and the dairy industry, which supplement the main occupation of agriculture in the Upper Ganges plain chiefly account for the greater prosperity of the small farmer in this area. Religious cult as well as popular superstition have contributed to spare and protect monkeys, as well as snakes, since the earliest days, even though the former may pillage orchards and the latter kill men by their poisonous fangs. In certain areas protection is also extended to the black buck which, roaming in large herds, ravage the crops.

INDISCRIMINATE KINDNESS. AND ITS PENALTIES.—Generally the spirit of *ahimsa* or pious harmlessness, which forms an integral part of popular Hinduism, has afforded protection to parrots, sparrows and other grain-eating birds; and to rabbits, rats, mice. and herbivorous animals in general, which have multiplied enormously on account of the bounty of the fields and the friendliness of the villagers, despite the damage they cause to the standing crops, and stored food-grains and fodder. All these animals show various degrees of adaptation to human surroundings. Some have become man's servants; cattle, buffalo, horse, sheep, goat, monkey, and even bear, either as useful animals or as pets; some have become pauperised dependents, as the half-wild dog, parrot, and squirrel, while a good many have become pests. The process of this conversion is universal and has been described by H. J. Van Cleave in these terms: "Man's chief influence upon plant and animal life has been in the direction of disturbing the Balance of Nature. Few animals in the wild state can endure contact with man. Close association with him usually spells either extermination or some

degree of domestication. Depending upon the basis along which the new adjustment is made, the animal becomes either a servant, a pest or a pauperised dependent upon his human associate. Flies, bed-bugs, rats and mice, and the hordes of insects attacking crops and stored food-stuffs have become pests as the consequence of surviving the relationship with man. They have become successful competitors with man in the new artificial environment which man has created. Their present day condition stands in sharp contrast with that of the swans, the deer, antelope, bison and dozens of lesser forms which have retreated before the advance of human frontiers and were unable to become adjusted to the new environment created by man and including the human species." Many of the pests not only find the man-made environment more favourable than wild nature and multiply enormously, but also do increased harm, since crops, stored food-grains, and domesticated animals are all found massed together in small areas. In most cases man, too, has been affected very unfavourably. In the villages there is an enormous congestion of houses due to lack of house-sites, the persistence of the joint-family system, and, generally speaking, greater cohesiveness. Very often the cattle have no independent shelter but are quartered in rooms adjoining man's. Such congestion has been seen in some area of the Ganges Plain that men and cattle sleep together in the same room. On account of the deposition of garbage, cattle manure, and rotting organic matter the numbers of the common house fly have gone up enormously in Northern India. In houses, in cattle sheds, in shops and in dirty lanes where the gutters open, man has furnished suitable breeding-places without number to the house fly (musca domestica) which is so closely connected with the epidemics of cholera, dysentery and typhoid fever, which periodically visit the villages and sweep away thousands. The congestion of population in villages, with consequent storage of food grains and abundance of waste vegetable materials, has led to enormous multiplication of rats, which have adopted habits bringing them into close contact with man. This has led to serious

plague epidemics which visit some parts of the Ganges plain regularly every year, carrying off thousands of the population. The etiology of plague is well-known. Plague is caused by a bacterium which thrives in the blood of rats and is carried to man by fleas. At the death of a rat infected with plague, its fleas abandon the carcass and seek some other warm-blooded animal. When the flea bites a man or any animal, such as a mouse, cat, squirrel or monkey, it voids. Thus man or any other animal, by scratching carries its fœcal matter along with bactetria to the wound caused by bite. In Indian villages and cities, Patrick Geddes has recommended the erection of pigeon-cotes whose inmates would promptly devour the inevitable crumbs and waste food materials, which attract rats. The fewer rats, the less plague. Further, the rat nurtures the nematode parasite, which causes the disease of trichinosis in pig and man. Agricultural expansion has increased the food supply and consequently multiplied rats. Rats thus abound not merely in the villages, but also in the cultivated fields, especially in the light-soiled tracts, where they do great harm to the crops. They nibble down the stalks to get the grain, which they store in large quantities in their holes. In some districts of the United Provinces, during the famine of 1897, the starving people supported themselves by digging up the grain stored by the rats.

In the areas where man's fields and house-sites have approached marshes and swamps, malaria, which depends on the abundance of mosquitoes which breed there, has become endemic, while in the canal-irrigated areas also, where there is waterlogging and the natural drainage has been disturbed, fevers have become rife. Malaria and *kalaazar* sometimes lead to the abandonment of whole villages, as in some districts in Western Bengal and Assam, and the jungle again rehabilitates itself, and in its wake reappear the predaceous animals, both large and small. Man—Marsh—Mosquito—Malaria — Jungle—Beast of Prey:—such are the stages of decline, which starting with man, return through the worlds of inanimate and animate nature, until the primitive savage equilibrium is restored.

As a result of the considerable bio-ecological changes which have taken place in the region, man (and his domesticated mammals) and insects have now become the most important among the animal communities of the region. In natural regions mammals and birds are usually most important, the former in the prairie and the latter in the forest. Man has directly exterminated many of the larger mammals. The expansion of cultivation and over-grazing of man's flocks have circumscribed the habitat, food and shelter of many species of mammals which have been reduced in numbers or swept off accordingly. Thus Nature's balance is upset. With the destruction of vertebrates, insects are now able to occur as predominants in the region. As man has lived in large aggregations, as he has grown special crops like wheat, cotton, and sugar-cane over large areas, as his domesticated stocks have thriven and are maintained in large herds, as his food stores and organic waste products have become more abundant, the invertebrate population has also multiplied. The increase of insect population is a menace to man's prosperity, as abundantly proved by the epidemics of plague, cholera, malaria and filaria, which decimate periodically a considerable number of human population, and also by such cattle epidemics as rinder-pest and heliminthiasis which it has become a serious problem for man to control. In this age of man and insects, the victory is thus not always on man's side. Man with his science and foresight has often used one part of animate nature against another. Thus he has introduced the sparrow to subdue the caterpillar, but this had unforeseen consequences which ultimately proved harmful. On the whole, however, his knowledge of the biological control of insects and pests has proved invaluable in his struggle for supremacy with the invertebrate population, especially in the hotter regions of the globe. Man has wandered all over the globe to find the appropriate natural enemies of the insects and parasites which damage his crops and fruits or bring deadly diseases for himself and his flocks. Thus man has introduced and propagated the native enemies of the fluted scale, the gipsy moth and other pests,

and is to-day in search of the natural enemy of the tsetse fly or the mosquito, which transmits the sleeping sickness or the yellow fever and malaria. In this region due to man's upsetting of nature's balance, or his curious discrimination, the multiplication of rabbits and squirrels, rats and mice, *langurs* and monkeys has meant a heavy drain of man's food-supply; while ticks and mites, mosquitoes and flies, voles, bugs and beetles (—) all now seriously threaten man's health, security and prosperity. Even man's toleration of useless cows and worn-out bullocks enjoined by religion has indirectly reacted unfavourably upon the breed and efficiency of the better types of cattle. The jackal and the swine, the crow, the kite and the vulture, towards whom man has been equally friendly, have served as man's useful scavengers. But the chief aid which man has derived from animate nature in the region, apart from his plough and draught cattle is from the nutrifying bacteria which he has nursed in the legumes, like *arhar* and *sann*-hemp, that normally rotate with cereals in his fields and save the latter from exhaustion in spite of centuries of continuous cropping. Further, the Northern Indian peasant obtains the spontaneous aid of soil bacteria, which accumulate enormous quantites of nitrogen immediately after the first monsoon rains and at the beginning of winter, which coincide with the commencement of his two agricultural seasons. Thus some bacteria, appropriate to particular legumes or freely occurring in river silt in diffused light, make agriculture possible for a dense population without soil exhaustion and thus materially contribute to man's dominance; while others levy an enormous toll on human and animal lives, and challenge the supremacy of man in the region.

MAN'S FLUCTUATING EQUILIBRIUM WITH NATURE.—The inter-relations between different species of animals and of men in this region are very intimate and elaborate, due to the enormous human pressure, and the examples of interactions which have been given above are but a few out of the enormous number which exist. Yapp observes: "We may perhaps regard the organisms, both plants and animals, occupying any given habitat, as woven into a com-

plex but unstable web of life. The character of the web may change as new organisms appear on the scene and old ones disappear during the phases of succession, but the web itself remains." An insect ecologist thus supports the above statement of the plant ecologist: "Evidently there is actually no such thing as a balance of nature, a true equilibrium; on the contrary there is continual fluctuation with wider or narrower limits. The so-called equilibrium is simply a condition of relatively small fluctuation. Under conditions of nature, animals and plants approximate a condition of stability, or fluctuation, within comparatively narrow limits, to the benefit of all concerned. Under artificial conditions, however, as when man grows one kind of plant over a large area, the insects of the plant multiply rapidly. Man is able to remedy such disturbances of the 'order or nature' in proportion to his knowledge of the factors, especially of their relative importance." Through the centuries man's heavy hand has in the Ganges plain set in motion a complicated cycle of oscillations in the life of inorganic and organic nature. Such oscillations are too numerous to be detailed, and sometimes too intricate to be comprehended. But what are ripples and cross-currents in the ocean of nature introduced by man deliberately or carelessly become waves when there is a succession of droughts, which lead to the limitation of food-supply for all creatures, great and small. In Northern India these correspond roughly to eleven-yearly cycle of sunspot activity, which exhibit the normal cyclic periods of bad harvest and shrinkage of vegetation and food-supply, and of extreme depression and reduction of animal populations. It is then that the ripples assume the proportions of mighty waves following waves, and man with the rest of organic nature has to submit to their fury.

CHAPTER VIII.

OPTIMAL AND LIMITING FACTORS IN AGRICULTURE.

CLIMATE, RAINFALL, AND AGRICULTURE IN THE GANGES VALLEY.—The characteristics of rainfall and irrigation of the natural regions into which the Ganges valley is divided may now be compared, and an explanation found for the agricultural contrasts of the distinctive regions, which are due chiefly to the conditions of water-supply, and which underlie the distribution of population.

On the Upper Ganges plain we have a continental climate of a pronounced character, hot summer alternating with cold winter. There is a clearly defined alternation of rainy and dry season. Moving westward, we find, both the length of the rainy season and amount of rainfall diminish. The annual precipitation varies from 25 to 30 inches and is much less evenly distributed than in the eastern portion of the plain. There are two contrasted agricultural seasons, *kharif* and *rabi*. In the *rabi* the wheat and barley dominate, depending mainly upon canal-irrigation. The mean "rain factor" here is 35. It is a meteorological peculiarity of the Ganges Doab, that, more than any other part of India, with the sole exception of the arid tract farther west, it is peculiarly subject to vicissitudes of rainfall. Thus the least deviation of the monsoon first registers its effects on this portion of the plain, whatever may be the fate of other portions. This region has also the world's greatest canal system, which is responsible for altering the whole character of its cropping and distribution of population. Canal-irrigation has reached its limit, and the growth of agricultural prosperity has now been eclipsed by the progress of agriculture in the eastern districts with superior advantages of rainfall and well-irrigation, coupled with an arranged succession of leguminous crops with rice. Strong, hot and intensely dry winds blow from the west with great persist-

ence during summer, and traverse the entire plain up to the boundaries of Bengal. These have a marked effect on the summer vegetation, which becomes the less prominent the nearer we approach the moister conditions in the east. Another effect of the strong winds from the west is the increase of less and sandy waste, which has been experienced especially in the south-western districts.

In the Middle plain (central portion) wheat and barley diminish in importance. Dominance of the rice crop follows a rainfall between 40 inches and 50 inches, and accompanies higher rural density than the normal. Agricultural certainty is yet ensured by the wheat and barley crop based on *jhil*, tank, or well irrigation. The last is much easier and cheaper than in the Upper plain, owing to the higher water-level, and has now reached a limit in some of these rice districts. This region, indeed, exhibits the most phenomenal expansion of the well system in the world. A slight fluctuation, however, in the amount and character of rainfall leads to shrinkage of the normal *kharif* area, and reacts unfavourably on the general condition of the peasant. Well-irrigation is of little avail for the protection of *kharif* in the event of a bad monsoon. This is rare, but when it occurs even the *rabi* is endangered, since the land cannot be tilled, and the region then is exposed to famine conditions.

In the eastern portion of the Middle plain, including Bihar, the climate is moister than in the central portion, and is to a certain extent transitional between the climate of the Upper plain and that of Bengal. An earlier monsoon gives three instead of two seasonal crops. The rainfall in winter is less than on the plain farther west. In North Bihar the average rainfall is 53 inches and in South Bihar 45 inches. Dominance of the rice crop accompanies lower rural density than the normal. Rice is of two varieties, early and winter. The dominance of the latter implies greater insecurity and risk from famine. *Rabi* crops here co-exist with greater agricultural security or immunity from famines, and greater density of population than the normal.

The *rabi* crop differs, however, materially from that in the westerly regions. Wheat is of far less importance. *khesari*, which is responsible for much of the *rabi* acreage, is principally grown as a second crop after rice. Well and tank irrigation are far less developed than in the United Provinces. Agricultural prosperity is bound up not with the rice harvest, which like the *kharif* in the United Provinces cannot be saved by irrigation in case of a bad monsoon, but with the *rabi* crop. As in the United Provinces, the *rabi* depends upon irrigation. Here private canals, tanks, wells and *bils* are far more important than the Government canals.

The climate of the deltas is characterised by unvarying warmth in conjunction with a uniform damp atmosphere. Rainfall is abundant, certain and better distributed, and the temperature is more equable than in the western part of the plain. There is a direct correspondence between the double-cropped area and the population density, but the influence of rainfall, which is both high and constant, is less evident. Unlike the United Provinces and Bihar, agriculture is not entirely dependent upon local rainfall. Floods play a more important part than rain in the fortunes of the wet region crop, rice. The delta rivers, with their timely inundations, are responsible for an arranged succession of three rice crops, along with pulses, jute, and vegetable, which is nowhere endangered by an unfavourable monsoon, nor needs the assistance of deep well-irrigation.

In the western and central portions of the delta, however, alluvial formation has been completed and the rivers have ceased to be active. Here crops, never so abundant, depend mainly, as in the more westerly portion of the valley, on the amount and distribution of local rainfall.

ECOLOGY OF THE GANGETIC POPULATION.—The above survey of climatic and agricultural conditions gives us the following ecological limits which govern the distribution of population:—

(1) In the Western and Upper part of the plain the limiting factor in agriculture is represented by a rain-

fall of 30 inches and an index of aridity of 20. Such an index is arrived at by dividing the annual precipitation (in millimetres) by the mean annual temperature in degrees centigrade, plus 10. (This may also be represented as a monsoon factor of 35 arrived at by dividing the rainfall in millimetres by temperature centigrades). According to Professor de Martoune, to whom we owe the making of such indices, indices of aridity about 10 correspond with the dry steppes; those of 20 more or less to the prairies; above 30 forest vegetation tends to dominate. Irrigation under such conditions fails to affect density. Irrigation below a limit of 25 per cent. of the gross cultivated area ceases to be a factor at all in determining agricultural productivity and rural density:

Districts.	Rainfall.	Irrigation (Percentage of gross cultivated area irrigated).	Double cropping (Percentage of double cropped to cultivable area).	Density.
Banda	37·95	5·4	7·3	206
Bijnor	43·9	6·9	5·5	395
Hamirpur	35·81	7·5	4·6	192
Jhansi	34·3	10·2	6·9	166
Jalaun	39·0	12·9	6·0	262

Here low density co-exists with small irrigation facilities, even though the rainfall is not deficient.

Irrigation above the limit of 40 per cent. fails to affect density unless the rainfall exceeds, 30 inches.

Districts arranged in the order of density.		Rainfall.	Irrigation.	Double Cropping.	Density.
Aligarh	..	25·08	48·1	18·6	545
Bulandshahr	..	25·86	45·4	24·7	560
Etah	..	27·49	41·5	16·9	482
Meerut	..	28·12	47·7	18·8	652
Mainpuri	..	29·84	50·6	8·9	446

Here density is relatively low though irrigation facilities are not deficient.

Lastly, mere amount of average rainfall, even above a limit of 40 inches, without the aid of irrigation, fails to contribute to high density.

District arranged in the order of density.		Rainfall.	Irrigation.	Double Cropping.	Density.
Benares	..	39·	31·1	22·4	898
Ballia	..	41·1	28 3	23·8	679
Azamgarh	..	41·1	45·0	20·1	690
Bijnor	..	43·9	6·9	5·5	395
Bahraich	..	43·6	7·1	7·1	402

High rural density exists in districts where rainfall is above 30 inches and where the irrigated area is high; *i.e.*, at least above 40 per cent. of the gross cultivated area:—

District arranged in the order of density.		Rainfall.	Irrigation.	Double Cropping.	Density (Rural in parentheses).
Benares	..	39·6	31·1	22.4	898 (704)
Jaunpur	..	41·8	45·5	21·1	745
Gorakhpur	..	48·3	28·8	22·7	721 (690)
Basti	..	48·0	35·0	26·8	687
Ballia	..	41·1	28·3	24	679
Fyzabad	..	40·06	40·0	26·4	676
Meerut	..	28·09	47·7	18·8	652
Bulandshar	..	26·00	45·4	24·7	560
Aligarh	..	25·00	48·1	18·6	545
Agra	..	25	25·2	7	498
Cawnpore	..	32	35·3	14	485
Budaun	..	32·8	10·1	14	484
Muttra	..	23·4	35·7		427

2. Throughout the United Provinces it is both rainfall and irrigation which together govern primarily the proportion of cultivated area, and secondarily the density of rural population.

3. This part of the plain is more susceptible to the fluctuations of the monsoon, which have violent reactions, especially on the *kharif* area. Most canals are *rabi* works and, though the *kharif* areas are even better protected by wells, the least disturbance of the amount and character of the rainfall spells conditions of shrinkage of cropped area and scarcity.

4. Coming to Bihar, the rainfall averages 49 inches as compared with 34 inches in the United Provinces. The early summer crop, like the *kharif* in U.P., is subject to

similar fluctuations. As in the United Provinces, immunity from famines depends on the acreage under *rabi,* which also has a direct positive correlation with rural density. The United Provinces mainly depends on canals and Bihar upon wells for the *rabi* crops. But Bihar, though favoured with a higher average and more evenly distributed rainfall, is less adequately protected by canals, and her well-construction also falls much below the limit reached by the United Provinces, especially in the eastern districts. Thus the Tirhut division, which resembles the eastern districts of the United Provinces in its dependence for rice on early monsoon, is one of the worst famine areas in India.

5. In Bengal the rainfall average 76·54 inches. But the early rainfall is not certain. Hence density increases with less dependence upon the summer rice crops, *aus,* whose success depends upon a favourable early rainfall.

6. The delta may be divided into moribund and active upper and lower portions. The great delta of the Ganges and the Brahmaputra has moved gradually to the east. The movement of the Ganges eastward is probably due to the denudation of trees on the hill-slopes in north and west, which caused an early silting up of old channels, and also floods Barind (North Bengal) and Rarh (Western Bengal) were settled and populated much earlier. Throughout a large portion of the Bengal delta the process of land-formation has ended and rivers have not only ceased to enrich the land with annual deposits of silt, but actually cause disease by becoming stagnant and choked with weeds. When the Ganges, probably in the sixteenth century, quitting the Bhagirathi, once started eastward, it may in time have successively found its main outlet through the channels of the Jalanghi, Mathabhanga, Kumar, Nobogunga, and Gorai; but its advance was continually farther east, leaving the off-takes to the west to dwindle and decay. It was through these five connecting links that the water of the Ganges, spreading over the delta, has already raised it. The process on the

western side and in the centre is now more or less an accomplished fact; on the east it is in rapid progress.[3] Thus in Central and Western Bengal, such districts as those of Murshidabad, Nadia, Jessore and the Twenty-four Parganas have been raised for the most part above the level of periodical inundation by silt deposit. In Northern Bengal, too, the same process is at work. The rivers have been silting up their beds, the land is water-logged, and epidemics of malarial fever have been serious and prolonged. In these areas man is now fighting a losing battle with natural forces of deterioration and disease. Eastern Bengal, on the other hand, forms a portion of the active delta; it is a wide alluvial expanse of open drainage and delta-building rivers, whereas the greater portion of the rest of the province is characterised by a moribund river system and obstructed drainage. Consequently Eastern Bengal is now the most populous and most productive portion of the Ganges valley; it is here that we meet with the most densely populated rural areas in the world. Further, towards the Bay, the soil fertility increases owing to the inundations from three river systems. The difference in soil types, as represented by the old and the new alluvium and the remoteness or nearness of the active silt-laden rivers, for the most part accounts for the difference between agricultural depression in Central and Western Bengal and prosperity in Eastern Bengal. In East Bengal, not merely is the tract enriched by the detritus from three different river systems, but also the average rainfall increases along the eastward courses of the rivers. Thus, both the double-cropped area and the area under *aman* increase and co-exist with greater rural density. Practically the whole of the arable land in the districts of Bakarganj and Noakhali, for instance, is in winter one smiling field of *aman* paddy; in these districts again the wealth derived from orchards, such as those of cocoanut, areca nut, etc., which grow most successfully in a high sandy soil rich in salt, is a further encouragement to high rural density, as in Cochin and Travancore.

(3) Vide *Report of the Drainage Committee of Bengal*, 1907.

7. The early summer crop is most uncertain under monsoon conditions. The dominance of this throughout the entire area of the Gangetic plain spells agricultural insecurity. The winter crop is governed by canal-irrigation in the western portion, by well-irrigation in the middle portion of the plain and by flood-irrigation in the deltas. Differences of mean temperature in different agricultural seasons diminish progressively from the continent to the sea. The contrasts in croppings due to temperature and rainfall conditions gradually disappear, and finally we enter a region of an elaborately arranged succession of croppings which is responsible for phenomenal agricultural productivity, leading to the world's highest records of rural density.

8. The maturity of the plain leaves its impress upon both the nature and the rotation of crops. The old alluvial soils naturally have to depend on artificial manures to maintain their fertility, while the new alluvial soils are periodically replenished by silt deposits from the overflowing rivers. Given artificial manuring and irrigation, the standard of farming is, generally speaking, much higher and the cropping more variegated on the old alluvium than on the new. When we approach the delta fringes manure plays a decreasing role in farming, till we reach areas where the value of any given field is determined not so much by the soil as by the depth of the water which stands on it during the rainy season. Secondly, in the tract covered by the new alluvium, the periodical deposits of river silt maintain a perfectly level surface adapted for rice cultivation. The surface of the old alluvium, on the other hand, is broken by the scouring action of the rivers and of surface drainage, and the level of the country rises and falls in parallel waves at right angles to the watershed, the crest of each wave lying between two rivers. Rice cultivation here is carried on by building an elaborate system of low embankments or small terraces, which hold up the rain-water for irrigation. Where this is impossible, or uneconomical, wheat, *gram* and millets supersede rice. Thirdly, even in the delta the distinction between the old and the new alluvial soils is discernible. In less

recent alluvial areas in Bengal the land surface is uneven and broken by ridges.

QUESTIONABLE RECONSTRUCTIVE MEASURES.—Large *bunds* or tanks made on the slopes of undulating country to hold water for rice irrigation were as numerous in the past in Western Bengal as they are to-day in Agra or Bundelkhand. Here also the problem of soil-erosion, due to the destruction of widespread *sal* forests has arisen, with its concomitants of increased aridity and floods. Owing to soil-erosion in wide areas in Western Bengal water, which should have percolated gradually through the soil of the upper slopes is no longer available, thereby causing the rice crops on the lower slopes to suffer from lack of moisture. Moreover, floods are more frequent, causing serious damage in the lower reaches of the rivers. It would appear that on account of rapid expansion of population in the Middle and Upper Ganges valley the Bengal delta has become overcrowded. Many of the remedial measures which are now proposed seek to correct the natural effects of human expansion in the jungle near the source of the rivers, as well as natural interference with the wayward and devastating action of the deltaic rivers. Thus whilst population multiplies and ascends the plateaus and hill-slopes, deforestation proceeds and protective measures are called for to prevent or retard floods. As it intrudes on the Sunderbuns, the jungle which formerly had acted as an effective barrier against destructive sea-waves is cut down, leaving man and his village entirely at the mercy of storms. Lastly, a systematic flood and flush process, *bonificiazione,* is recommended, as in Italy, in areas where the conditions are now such that, if left to itself, the river will spill over the banks even in moderate floods. This system has been recommended for a very large area in Midnapore, as also for some areas in the Burdwan and Hughli districts.[4] The destruction of the *sal* forest and consequent soil-erosion, as well as the construction of embankments, have all contributed to upset the hydrographical equilibrium; and

(4) *Royal Commission on Agriculture in India*: Evidence, Vol. IV, p. 82.

this has reacted unfavourably, especially on Western Bengal. By the sixteenth century Western Bengal already possessed a dense population, and since then enormous expansion has taken place. This has made the process of an artificial interference with the river system of the delta inevitable, leaving to posterity a prospect of loss of fertility, water-logging, deterioration of rivers, fever, etc.

RAINFALL CONDITIONS FOR RICE AND JUTE.—What rainfall is the optimum, *i.e.,* best suited to the conditions of agriculture in the wet and dry low latitudes climate, where an aquatic plant like rice has been adapted in its innumerable varieties to the conditions of moderate and excessive rainfall, raises a very interesting problem. We take first the eastern deltaic region, where rainfall is heaviest and rice mostly is grown as the mainstay of an abnormally dense population.

Districts arranged in the order of diminishing rainfall.	Density.	Rainfall.	Percentage of Cultivable Area. Net Cultivated.	Double Cropped.
Jalpaiguri ..	319	142	61·5	10·5
Noakhali ..	972	114	87·0	31·9
Chittagong ..	645	113	85·2	8·2
Bakarganj ..	752	89	88·3	14·7
Mymensingh ..	776	88	86·5	26·2
Rangpur ..	770	80	72·7	5·2
Dacca ..	1148	75	94·1	20·1
Faridpur ..	947	73	97·9	14·8
Dinajpur ..	432	71	65·0	5
Bogra ..	760	66	61·7	32·7
24-Pargnas ..	541	63	59·7	10·1
Murshidabad ..	595	55	44·5	15·2
Nadia ..	535	55	44·7	17·1

The conditions are complicated by the fact that it is in the inundated alluvial tracts that we find a heavy rainfall. It appears, however, that a rainfall above 120 inches may be considered as excessive under the conditions of wet-crop cultivation in the region of the Ganges delta. An average precipitation of 70 inches to 90 inches and high relative humidity during the rainy season are here most favourable for the cultivation of rice and jute. A rainfall below 70 inches is accompanied by a relative diminution of the area under cultivation, and under more than one crop, and hence a diminution of rural density. In the

region of the Upper Ganges plain, rainfall is considered insufficient when it falls below 30 inches. A deficiency below this limit cannot be made good by irrigation, however extended it may be.

ECOLOGICAL AREAS—"EXPANSION RATIO" OF POPULATION.—We proceed to classify the ecological areas of the Gangetic plain and show their relation to the proportion of cropped area and the distribution of rural density. Each ecological area has for a given state of the arts of agriculture, a more or less definite population capacity, and also what Aurousseau has called an "expansion ratio", *i.e.*, the percentage which the present population bears to the maximum population that the ecological area can support. It is taken for granted that the standard of living also remains the same, however that might be expressed.[5] It is only in the active deltaic region of the Ganges Valley that at present the "expansion ratio" is positive. In the other four ecological areas the index shows the degree by which the population capacity has already been passed. Optimum density would represent the index at which the area may support the density under "optimum conditions", however these might be expressed. The table is supported not only by *a priori* probability, but also by a wide range of agricultural data, such as rainfall, irrigation, cropping, etc., as well as vital statistics.[6]

Ecological Areas in the Ganges Plain.

Warm Temperate Climate.	Rainfall. (inches).				Population,			
Wet and Dry Low Latitudes.	Excessive	Optimum	Insufficient.	Annual Range of Temparature.	Percentage of Gross cultivated area.	Mean Density per sq. mile.	Optimum Density per sq. mile.	Expansion Ratio per sq. mile.
Upper Ganges plain (Western).	60	45	30	78°F.	100	500	200	400
Middle Ganges Plain (Central).	65	38	30	75°F.	90	550	250	350
Middle Ganges Plain (Eastern including Bihar).	70	60	45	68°F.	110	650	300	400
Moribund Delta ..	100	65	60	64°F.	60	550	250	300
Active Delta ..	120	80	—	52°F.	420	875	1000	2000

(5) Aurousseau: "The Geographical Study of Population Groups," *Geographical Review*, XIII, April, 1923.

(6) A. B. Wolfe: "The Population Problem," *Ibid.*, Decr., 1928.

The above table may be contrasted with the following scale, which is related mainly to the conditions of cultivation of the cereal foods of Western civilisation and is based on studies of the distribution of cultivated land.[7]

		Rainfall	
		Excessive	Insufficient.
Cool temperate lands	..	40 inches	8 inches
Waram temperate lands	..	60 "	12 "
Hot temperate lands	..	80 "	18 "

We give below a table which shows the distribution of the world's rainfall.

		Under 20 inches.	20—40 inches.	Over 40 inches.
Africa	..	54 per cent. (largely hot)	18 per cent.	28 per cent.
Asia	..	67 per cent. (largely cool).	18 per cent.	15 per cent.
North Amercia	..	52 per cent.	30 per cent.	18 per cent.
Europe	..	47 per cent.	49 per cent.	4 per cent.
South America	..	16 per cent.	8 per cent.	7 per cent.

The following table illustrates the conditions in deserts and semi-desert region.

Climate Warm Temperate. Low Latitude.	Region.	Rainfall. (inches) Excessive	Insufficient.	Index of Aridity.	Mean annual range of Temperature.	Population Density (per sq. mile).
Desert	The Great Indian Desert.		10	3 to 10	90°F.	2-50
Semi-arid	The Rajput Upland.	40	15	10 to 15	82°F.	100-150

(7) Fawcett: "On the distribution of population over the land," *The Sociological Review*, April, 1925.

CHAPTER IX.

LAW OF DIMINISHING RETURNS BY LAND AND WATER.

River-Basins of South-East Asia.—The distribution of plants and animals is governed very largely by temperature and rainfall. We hardly realise the extent to which the environment similarly controls the distribution of mankind. We have dense populations where natural conditions are most congenial to man and the necessaries of life most easily obtained. The most heavily populated parts of the world are the hot monsoon lands of Asia and the lowland plains of the temperate lands. The hot region of South-East Asia enjoys the unique advantage of an abundant rainfall during summer, which is most conducive to vegetable growth. Thus this region is wonderfully productive and the most heavily populated on earth.

There are two sub-regions where population is densest. These are, first, the densely populated plains of China, where the monsoon rainfall, and the alluvial silt from the great rivers, are jointly responsible for a marvellous agricultural productivity. The four most densely peopled provinces of China are as follows:—

		China Continuation Committee's Estimate. 1918-1919.	Density of population per sq. mile. Post Office Census, 1920.
Kiangsu	..	872	875
Chekiang	..	624	600
Shantung	..	553	500
Honan	..	479	454

The provinces of China generally have been considered, so far, as the most heavily populated regions in the world. The two estimates of population given above represent the most scientific and probably the most reliable computation of the population of China that has yet been made. These, however, indicate that what credit

may be due for being the most densely peopled region in the world must be awarded to the Indo-Gangetic plain, where in some natural divisions we reach the phenomenal figures of 1,000 to 2,000 persons per square mile. In the three regions—the Northern, the Yangtse delta, and the Canton delta the density of population does not exceed 1,000 to the square mile. Similarly, in the plain of Chengtu, the scene of the most intensive irrigation in China, the density of population, according to one careful estimate, does not rise beyond 1,700 to the square mile. But in the Ganges plain the density in some areas reaches incredible figures, from 1,500 to 2,000[8]

There is another striking difference in the distribution of population in the plains of China and of India. In China the plains are very varied from the point of view of soil conditions and habitability. The density, accordingly, is very unequally distributed. The Ganges plain, on the other hand, is densely populated throughout. In the progress of the river-flow towards the deltas, however, the soil and climate become more and more favourable to agriculture and rural density, and in the deltaic districts we have the world's highest records of concentration of population along the waterways.

Now the concentration of population agrees very closely with certain universal principles derived from geography and ecology. These, indeed, suggest how materially ecology and geography can assist economics in interpreting the distribution of population. Ecology is the science of the adjustment of living creatures to the environment. The dependence of living creatures on climate and other physical conditions is greatest where the natural environment is most unfavourable, and where the multiplication of numbers has made the struggle for existence most acute. Fortunately for us, a survey of the

(8) Certain investigations carried out under the auspices of the China International Famine Relief Commission, which covered 65 villages in the rice-growing provinces of Chekiang and Kiangsu, showed, however, that the number of inhabitants to the square mile varies from 980 in some village, districts to 1,880 in others. In Shantung figures range from 1,800 to 3,000 and in the northern wheat-producing province of Chihli from 550 to 2,010.

Gangetic plain and of its borderlands accords the most favourable opportunity of studying at once the effects of the most favourable and the most unfavourable conditions of life on the density of population. It is in such areas that we may study the so-called relative "optimal" and "limiting" factors including Liebig's Law of the Minimum and its various modifications and the Law of Diminishing Returns. Agricultural water-supply serves as a limiting agent in population density and movement; and though we cannot give precise formulation to the limiting factors, useful generalisations, no less serviceable to the ecologic control of numbers by certain universal processes of action and interaction between the organism and the environment, can be reached.

DESERT AND DENSITY.—On the fringes of the most fertile valley of the world we have the Great Desert. It is in the environment of the desert that one can more clearly observe than elsewhere the interaction of plant and animal upon each other, and the dependence of all living creatures on climate and other physical conditions. In the desert we have the closest adjustments of living creatures to the component elements of the environment. The most remarkable examples of physiological adaptations arise, for instance, from adjustments to scantiness of water. Most animals of the desert require little water. Camels have been known to go two months without drinking. Some animals never drink, but obtain their water exclusively from vegetation or from other animals. Subterranean rodents find moisture in the bulbs and roots of perennial plants, and the sparse but succulent, thick-leaved growths characteristic of the desert's surface are often miniature reservoirs. Experiments carried out by Buxton have shown that even the dry fragments of vegetation blown about by the winds contain moisture upon which insects and small animals may thrive. These dry stalks are capable of absorbing water directly from the atmosphere when, as is often the case in the desert at night, the relative humidity rises above 80. Many of the animals of the desert avoid the

intense heat of the daytime by burrowing to cool, moist depths, and die when exposed to the sunlight or superheated sand, rock or gravel of the surface.

The desert is as hostile to man as it is to animals and plants. Normal agriculture is impossible in the desert, and man's life is a constant struggle for mere existence in the face of extremes of cold and heat, with the menace of drought and famine ever at hand, and of such aberrations of the climate as long droughts, torrential rains, sharp frosts, and violent whirlwinds. The marked seasonal changes breed the nomad. The nomad is wholly dependent on his flocks, around whose preservation the entire course of his life revolves. North-west of the Aravalli range in Rajputana, south of the plains of Northern India, there is a vast dry area, with a rainfall generally less than 10 inches annually, which slopes gradually towards the Indus valley and the Punjab plain. This forms the Thar or Great Indian Desert. It consists of a sandy waste interrupted by hills and waterless valleys. The ground is often entirely bare. Here and there grow a few desert shrubs and plants. Jaisalmer lies in the centre of the Thar, with an average rainfall of only 6·7 inches and is a barren desert. The people here are notably nomadic, depending on the herds of cattle, sheep and goats. Out of a population of 88,311, the number which is supported in this way comes to 19,810. Throughout Rajputana population is sparsely distributed, and the dictum holds good that a scanty rainfall means a scanty population. In the western division, which embraces the Great and Little deserts of India, the normal rainfall varies from 7 to 13 inches. Even this amount is very capricious and falls mainly during storms. Here the density of population is only 59 to the square mile. This spare population can be maintained with difficulty on account of the extraordinary variability and local character of the rainfall. The dry grass-lands are subject to visitations of famine. An ancient stanza speaks of this dread visitant in these terms:

"His feet are in Punjab.
His head is in Merta.

His belly's in Bikaner,
In forgetful moments,
He'll visit Jodhpur,
But he is always in Jaisalmer."

The soil here is often fertile, and if irrigated would, no doubt, in some parts at least, be capable of supporting as great a population as the canal colonies of the Punjab. No irrigation however, can be had at present, since no large rivers exist which can supply it. Even if rivers existed, irrigation would be difficult, owing to the irregularity of the land. In the decade 1891-1901, which was one of disastrous famines, the population in the western division was depleted by fully 25·4 per cent. where the variations in rainfall are most critical. The whole tract necessarily is subject to marked fluctuations in migration. A considerable portion of the population is, as we have seen, of the nomadic type, which moves backwards and forwards with its herds at the first signs of failure of rain, crops, or fodder. Villages spring up only where a little water is available, and millet and fodder can be grown. Often, however, the water in the wells fails or becomes brackish, and then the village has to be abandoned.

It is a curious fact that in the Indian desert we find a striking disparity between the proportions of the sexes. In most of the Rajputana states and districts the proportion of women in their actual populations is low; in Jaisalmer the ratio is the lowest, there being only 820 females to 1,000 males. A theory has been put forward that the ratio of females to males is depressed by a dry and hot climate, particularly if accompanied by a considerable range of temperature. It is probable that dietetic factors and strenuous toil in an inhospitable habitat also account for lower femininity. As a matter of fact the sex ratio becomes lower in northern India as we proceed from moist and fertile to arid and less productive regions. One effect of the rigorous environment, no doubt, has been that in the Western Division in Rajputana, which is the driest and hottest, there is less inclination among men to

take upon themselves the bondage of wedlock than elsewhere. The proportion of bachelors over the age of 15 is highest here. This tendency to celibacy is most marked in Jaisalmer state, where nearly half of the males between 20 and 40 remain unmarried. At the same time it seems extraordinary that the state with the lowest proportion of females also shows almost the greatest tendency to polygamy. Hypergamy and the desire to avoid social obloquy in the family when suitable grooms cannot be secured for girls who come of age may account for the association of polygamy with a low sex ratio among some of the Rajput tribes and castes. It is clear that both the hostile environment and the roving, fluctuating life of the people have produced such aberrations. Nothing can illustrate better the control of man by the environment.

South-east of the Indian desert there is the Rajput Upland region of hill, mountain and plateau, which embraces a number of native states, most of which played an important part in the history of Imperial Delhi. Sandy wastes extend from here towards north and north-east, and here and there may be found traces of rivers that have lost themselves in the sands, and of cities that the sands have overwhelmed. The region receives less than 25 inches of rain and passes gradually to the Ganges Doab, where the normal rainfall is nearly 30 inches and hot winds blow in summer. Here we have the economic and climatic frontier separating grazing country from cultivated plains. This often corresponds approximately to the twenty-inch rainfall line. The deficiency of rainfall here is not as serious in its effects on the wild grasses of the pastoral country as on the crops of the cultivated region. But when the rainfall is deficient over wide areas the drought limits extend to parts of the Doab fringing the arid regions of the interior. The Doab is also a hot and dry region, like the Rajput Upland region; but, while the latter is hilly and makes irrigation difficult, the former is one great plain, sloping very gently from Delhi (700 feet) to Allahabad (400 feet). The rainfall gradually increases in our passage down the Doab; and we can take the confluence of the rivers, through which the 40-inch rainfall

line passes, as the eastern limit of the dry region of the Upper Ganges plain.

GANGES DOAB AND INTENSIVE FARMING.—The Upper Ganges plain is now intersected by canals, and its agriculture has been revolutionised. The region is extensively cultivated and there has been an enormous concentration of human and cattle population. In proceeding farther along the course of the Ganges, we met more rain and a smaller range of temperature. Irrigation is also less difficult. The subsoil in many parts of the Doab, especially towards the east, is peculiarly favourable for well-construction. In the Rajput Upland region the staple food is millet; in the Upper Ganges plain wheat is introduced by canal irrigation, though millet also forms a very important crop, second in importance only to wheat; in the Middle Ganges plain, the wet region crop, rice, becomes more important than wheat, and supports a heavy population. An abundant rainfall in summer, a high and equable temperature, an annual inundation by the rivers carrying rich detritus from the Himalayas, an arranged succession of leguminous crops along with rice:—all these elements have contributed to make the Ganges Valley the most productive in the world. But man, by his unchecked multiplication, even in the most fertile valley, has increased his struggle for livelihood so portentously that the slightest disturbance of the natural conditions of agriculture produce violent reactions upon his standard of living and even his numbers. Throughout the Ganges plain the incidence of the density of population bears a close correspondence with the percentages of the net cultivated and the double-cropped area to the cultivable area. This will be clearly evident from the statistics of population, agriculture and water-supply of the typical districts in the different natural areas of the United Provinces:

UNITED PROVINCES, INDIA: ECOLOGICAL TABLE.

Comparative Percentages, Cultivated Areas.

Name of District (arranged according to natural regions).	Normal Rainfall. (inches).	Net cultivated to cultivable area.	Irrigated to irrigable area.	Area double cropped to total cultivated area.	Density to Population
Gangetic Plain, West					
Meerut ..	28·09	82·4	36·8	33·4	699
Bulandshar ..	26·0	80·5	49·8	31·7	595
Aligarh ..	25·0	79·9	60·2	21·5	602
Muttra ..	23·6	82·5	40·3	12·5	461
Gangetic Plain Central.					
Cawnpore ..	31·8	75·3	44·7	9·4	512
Unao ..	33·4	69·3	44·0	18·7	479
Pratabgarh ..	37·9	74·3	53·7	28·0	628
Gangetic Plain, East.					
Benares ..	39·9	82·6	68·2	22·8	930
Jaunpur ..	40·6	76·0	71·2	25·6	797
Azamgarh ..	40·4	77·3	79·9	26·2	710
Ballia ..	41·4	78·8	65·6	24·6	742

A limit seems to have been reached in the major portion of the plain in the direction of intensive farming. Most of the districts in the Western, Central and Eastern portions of the Ganges plain have reached more than 75 per cent. of net cultivated to cultivable area. Thus more and more the proportion of double-cropped or intensively farmed area govern the increase of population density.

That the population is outrunning the means of subsistence in the Upper Ganges valley is indicated by the fact that the density of population, district by district, increases at a greater rate than the proportion of land which is cultivated and the proportion of area cropped more than once.

Name of District (Upper Ganges Valley).	Percentage of variation of total cropped area. 1891-1921.	1921-1931	Percentage of variation of density. 1891-1921	1921-1931.
Saharanpur ..	2.1	−0·6	− 4·4	+11·4
Muzaffarnagar ..	8·7	+2·7	+ 0·28	+12·7
Bulandshahr ..	7·2	−1·1	−18·0	+ 6·9
Meerut ..	6·2	+2·02	+12·0	+ 6·6

This implies that there is a keener struggle for existence and a tendency towards a lower standard of living.

DRY STEPPE—IRRIGATION AND DENSITY.—The effect is, however, most apparent in those parts of the valley where the water-supply, which is the life of agriculture, is naturally deficient or exposed to violent seasonal flunctuations. Such effects will be found also to operate over more or less contiguous blocks—that is, natural entities where the temperature and water-supply bring about a similarity of geographical and other physical characteristics. We find that the south-western portion of the Ganges-Jumna Doab which fringes the semi-arid tract bordering the Great Desert has shown a decrease of density within the last three decades. It is most interesting to note that in the dry steppe tract of this Province, where the index of aridity is below 22 or 23, the artificial protection of agriculture by the upper and more reliable portions of the Ganges and Jumna Canals could not keep up the increase of population of the earlier period.

DRY-STEPPE—DENSITY VARIATIONS, 1865-1931.
(PER SQUARE MILE).

Name of District.		Index of aridity.	1865	1872	1881	1891	1901	1911	1921	1931	Actual density.	Variation in mean density between 1901-31.
Dry Steppe.												
Muttra	..	15·5	498	551	463	492	526	452	427	461	−65
Aligarh	..	17·0	498	547	525	536	617	599	546	602	−15
Agra	..	17·0	533	575	525	541	572	551	498	567	− 5
Etah	..	18·2	437	465	438	406	500·	504	483	501	+ 1
Prairie.												
Jalaun	..	——	262	260	270	256	258	261	262	275	+17
Mainpuri	..	21·2	420	452	578	455	495	476	447	448	−51
Etawah	..	21·5	384	395	427	430	477	449	434	442	−35
Cawnpore	..	22·9	504	495	498	510	531	482	485	512	−19
Unao	..	19·5	537	554	503	534	546	510	458	479	−67
Bulandshahr	..	1·	420	490	485	498	597	590	562	595	− 2
Meerut	..	21·2	513	541	560	593	657	648	653	699	+42
Muzaffarnagar	..	22·0	144	416	453	462	524	483	479	541	+17

Percentage variations of total cropped area and density between the period, 1891-1931.

Name of District.		Percentage of increase of total cropped area 1891-1921,	1921-1931.	Percentage of increase of density 1891-1921,	1921-1931.
Upper Ganges Valley:					
Saharanpur	..	+2·1	−0·6	− 6·2	+11·4
Muzaffarnagar	..	+8·7	+2·7	+ 4·1	+12·7
Meerut	..	+7·2	−1·1	+ 9·0	+ 6·9
Bulandshahr	..	+6·2	+2·02	+13·5	+ 6·6
Aligarh	..	+1·71	+1·9	+ 3·3	+10·4
Muttra	..	−3·3	+6·5	−12·7	+ 7·9

Name of District.		Percentage of increase of tolal cropped area. 1891-1921,	1921-1931.	Percentage of incerease of density. 1891-1921,	1921-1931.
Agra	..	—4·3	1·7	— 7·5	+13·4
Mainpuri	..	+ 0·9	—15·2	— 1·2	+0·2
Etah	..	+20·03	— 0·96	+12·2	+3.7
Etawah	..	+ 4·5	— 0·95	+ 1·6	+1·7
South West:					
Jalaun	..	+10·8	— 2·2	+ 2·3	+5·1

Agricultural Statistics of the districts of Aligarh, Muttra, Agra and Jalaun from 1891-1921, clearly indicate that the cropped areas have remained on the whole constant, though fluctuating from year to year; such fluctuations being the greatest in bad rainfall years. It is also noteworthy that the canal-irrigated districts follow the unprotected districts closely as regards the variations of cropped area. This indicates that canal-irrigation can assure no better certainty of crops under the conditions of a precarious rainfall than is available for the unprotected districts. This is due mainly to the increase of total cropped area as a result of the pressure of population, so that the amount of water which may be supplied by the canals is inadequate in years of unfavourable rainfall. A large amount of reclaimed land is also unsuitable for irrigation. In these particular districts the shrinkage of cultivated area and decrease of population density seem to go together, giving evidence of a losing battle with unfavourable hydrographical conditions.

Professor Pearl laid down the demographic law that, when population density reaches an equilibrium point, the death-rate exceeds the birth-rate, and we have a decline of population until the equilibrium is restored. We have an interesting corroboration of Prof. Pearl's principle from some areas of the Ganges plain. It would appear from the movement of birth and death rates of Muttra, Agra, Aligarh, Etawah, etc. that a tendency of mortality to be increasingly higher than natality is manifest. Of course different districts would reach the saturation density in different decades owing to different conditions of agricultural water-supply, and thus the decrease of population density has not been uniform. Such decrease of density has been seen with or without a shrinkage of the total area cropped in the district.

EASTERN DISTRICTS OF THE UNITED PROVINCES.—The eastern districts, which enjoy a more reliable rainfall than those of the south and west, have multiplied so largely that their position has become equally precarious so far as the maintenance of the present standard of living and even of numbers is concerned. In their cases, too, density of population primarily depends on the proportion of land which is cropped more than once, the percentage of net-cultivated area having reached nearly 80 per cent. of the cultivable area. Notwithstanding the excellent and timely famine insurance that these districts provide by means of an extended system of well-irrigation, which explains the much smaller shrinkages of cropped areas in famine years than in the south and west, the density of population here also shows a tendency to decrease. This is shown in the following table:

EASTERN UNITED PROVINCES, CULTIVATION AND DENSITY, 1891-1931.

District.	Percentage of area cropped more than once to total cultivated area.	Percentage of well-irrigated to total irrigable area in the last famine year.	Percentage of increase of total cropped area including area cropped more than once.		Percentage Variation of density.				
		1918-19	1891-1921	1921-31	1891-1921	1901-11	1911-21	1891-1921	1921-31
Gorakhpur ..	32·8	52	+ 4·7	+1·2	− 1·2	+8.9	+2·1	+ 9	+9·8
Basti ..	37·3	34	+ 8·9	+2·08	+ 3·4	+0.9	+5·2	+ 8	+7·8
Azamgarh ..	26·2	57	+15·7	+1·3	−11·4	−3.6	+2·4	−13	+2·8
Janupur ..	25·6	86	+ 4·7	+2·9	− 4·9	−3.9	−0·1	− 9	+7·0
Benares ..	22·1	92	+24·7	+12·1	− 4·7	+1.1	+1·8	− 2	+6·2
Ballia ..	24·6	55	+15·6	−1·7	− 0·8	−1.4	−1·7	−15	+9·9
Ghazipur ..	16·9	45	+ 4·4	−2·8	−10·8	−8.1	−0.9	−19	+5·6

Agricultural Statistics show no doubt a steady tendency towards expansion of total area cropped, but the expansion of population density is disproportionately large in the cases of the newer districts, such as Gorakhpur and Basti. This will be evident from the following figures:—

District.	1881	1891	1901	1911	1221	1931
Gorakhpur	574	657	649	707	722	787
Basti	582	637	659	653	687	737
Benares	885	914	875	890	899	930
Azamgarh	733	790	700	675	691	710

If Benares and Azamgarh show a decline in their density of population from 1891, in spite of a steady extension in the total area cropped (including area cropped more than once) and an extension of well-irrigation, which in years of drought have reached the phenomenal figures of 95 and 93 per cent. respectively to estimated irrigable area, does it not support the inference that owing to the enormous pressure of population on the land man's efforts are here showing a diminishing return, and population is receiving a set-back?

It is only the districts north of the Gogra, which are naturally protected by a heavy and reliable rainfall and where irrigation is easy on account of the high water-level, that are still maintaining an increase of population. During the thirty years, 1891-1921, the density of population in Gorakhpur and Basti respectively has increased four and one and a half times more than the total net-cropped area (including area cropped more than once). Obviously the very multiplication of population will sooner or later bring them into a line with the southern and eastern districts, where the phenomenon of decrease of population and a lowering of the standard of living would not have been experienced under favourable conditions of soil and water-supply but for redundancy of mouths to feed.

It is in this manner we realise that, if we take several decades, the effects of variations caused by disease, such as plague, malaria and influenza might be minimised; and the variations would reflect permanent tendencies. A tendency towards a shrinkage of population has appeared even in the most favoured area of the world. Towards the south and the west of the plain this has been due predominantly to arid conditions and to famine, which these imply in years of a deficient or irregular rainfall. In the middle and eastern portions this shrinkage simply indicates that the optimum density of population has been overstepped. Thus the least variation of the amount and distribution of rainfall, which would not have had any

effect if these portions were less heavily populated, now has violent reactions.

DENSITY IN BIHAR.—These reactions on man's numbers and his standard of living are visible also in Bihar, but become less evident towards Bengal.

In Bihar the symptoms of over-population are clearly visible. A succession of good harvests is followed, as in the United Provinces, by an increase in the number of births and gradual fall of mortality. When the harvests are short and the price of food grains rules high, the birth-rate rapidly declines and the mortality rises. This will be evident from the accompanying table.

RELATION BETWEEN AGRICULTURE AND PUBLIC HEALTH: BIRTH AND DEATH RATES IN NORTH AND SOUTH BIHAR.

	1906		1912		1918		Average of two decades: 1901-1920		1924		1930		Average of decade 1921-1930	
	Male.	Female.	Male.	Female.	Male.	Female.	Male.	Female.	Male.	Female.	Male.	Female.	Male.	Female.
North Bihar:														
Birth rate ..	40	36	45	41	40	35	42	37·5	35	32	34	32	36	53
Death rate ..	41	35	37	32	60	52	38	33	31	27	35	31	27	24
Survival rate ..	−1	+1	+1	+9	−20	−17	+4	+4·5	+4	+5	−1	+1	+9	+9
South Bihar:														
Birth rate ..	45	41	48	44	42	38	44·5	40·5	42	39	42	40	41	39
Death rate ..	44	40	33	31	70	69	41·0	39·0	33	31	33	33	31	29
Survival rate ..	+1	+1	+15	+13	−28	−31	+3·5	+1·5	+9	+8	+10	+10	+10	+10

Throughout a large portion of Bihar the volume of emigration also corresponds to the state of the harvests. If the harvests are good, the emigration diminishes, if they are bad it is larger and lasts longer. The close adjustment of human numbers to the food-supply is clearly shown, not only by such phenomena, but also by the correspondence between rural density and the percentages of double-cropped area to total cultivated area, the latter assuming a phenomental figure district by district.

CULTIVATION AND DENSITY, BIHAR, 1891-1931.

District and natural area.	Percentage to cultivable area of: Net cultivated	Double cropped.	Percentage Variation of total area cropped (including area cropped more than once) between 1891-1921.	1921-31.	Percentage Variation of density. 1891-1921.	1921-1931.
North Bihar:						
Muzaffarpur ..	81·5	55·3	+15·8	+6·9	+1·5	+6·8
Saran ..	72·6	44·4	+10·0	−13·1	−5·1	+6·3
Darbhanga ..	85·7	31·2	+5·37	−19·1	+3·9	+8·7
Bhagalpur ..	64·7	22·8	−12·0	−6·9	+0·3	+9·9
Purnea ..	59·9	11·6	+8·7	−15·8	+4·7	+8·2
South Bihar:						
Patna ..	64·7	29·0	−1·6	+12·6	−11·3	+17·1
Shahabad ..	76·4	16·2	+11·2	+5.2	−12·3	+9·9
Monghyr ..	73·4	21·6	+10·75	−3·4	+4·7	+12·7

The above table shows that the density of population depends upon the proportion of land which is cultivated and upon the proportion of double-cropped area, and that the density of population increases at a greater rate than these proportions. This indicates that the law of diminishing returns is operating. Indeed the slightest disturbance of agriculture brings about conditions of famine and scarcity in a large portion of heavily populated North Bihar.

Crop areas show enormous fluctuations in the Bihar districts in response to the amount and distribution of rainfall. This indicates a more precarious agriculture than that of the eastern districts in the United Provinces, for instance, where the climate and rainfall are similar to Bihar. The difference is due solely to the fact that wells, which have proved a useful and valuable resource in bad rainfall years in the United Provinces, are not so numerous in Bihar. It is noteworthy that Bhagalpur, which shows most violent oscillations and a tendency towards permanent shrinkage of cultivated area, is least equipped with the well system of irrigation, and yet most dependent upon rainfall for her early monsoon crop.

All the more heavily populated districts in Bihar now exhibit a tendency towards a stationary condition or even

decline in the density of population; the cultivated area shows violent fluctuations, and the precariousness of agriculture has already left its impress upon declining numbers.

CULTIVATION AND DENSITY, DELTA OF THE GANGES, 1891-1931.

District and natural area.	Percentage of cultivated area to net Cultivated crop.	Double crop.	Percentage variation of total area cropped (including area cropped more than once) between: 1891-1921	1921-31	Density of population. 1931	Percentage Variation of density. 1891-1921	1921-31
Moribund Delta:							
Burdwan ..	54·0	15·5	34·9	−15·6	583	+2·9	+9·5
Hooghly ..	62·3	2·5	·55·7	−3·6	938	+4·4	+3·1
Murshidabad..	44·5	15·2	·42·9	+44·0	656	+1·8	+10·2
Nadia ..	44·7	17·1	·15·7	−4·4	531	−8·9	+ ·8
Jessore ..	85·4	4·3	·21·8	−11·8	576	−8·3	−2·9
Active Delta:							
Bakarganj ..	88·3	14·7	+39·5	+1·3	834	20·6	+12·9
Faridpur ..	97·9	14·8	+16·8	+4·0	1003	19·6	+ 6·4
Daccas ..	94·0	20·0	+21·6	+14·9	1256	30·8	+ 8·7
Mymensingh..	86·5	26·2	+3·1	+2·6	823	35·1	+ 6·1
Noakhali ..	87·0	31·9	+9·3	+8·3	1124	40·1	+15·9
Tippera ..	93·3	40·2	−14·4	+2·5	1197	43·2	+13·3

DELTA, MORIBUND AND ACTIVE.—When we reach Bengal, such reactions cease. The unique advantages of water-supply which the deltaic peasant enjoys can maintain so far a high standard of living in spite of multiplication. Yet even in the delta the concentration of population along the waterways continues at such a rate that the optimum will be overtaken in a few decades more.

In the Lower Ganges valley, the disparity of economic progress between the moribund delta of the Ganges and active joint delta of the Ganges and Brahmaputra rivers, where the fertility of the soil is replenished yearly by deposits of silt, will be evident even from a casual survey of the figures of density of population and net cultivated area. As in Bihar and the United Provinces, we find a correlation between double-cropping and density of population. The districts in the moribund deltaic area in Bengal show much smaller percentages of both net-cropped and twice-cropped areas and rural densities than those in

the active delta. Both agriculture and population in Western Bengal have received a set-back due to the cessation of the delta-building activities of the Ganges and her tributaries. The agricultural statistics representing the increase of gross cultivated area in Bakarganj and Dacca show a refreshing contrast with those for Jessore and Nadia, where barrenness and deterioration have set in. The population of Bengal rose by 33 per cent., between the years 1872 and 1901; and between 1911 and 1921 by 2·8 per cent. only. There have been local instances of crop failure, but nowhere in India has famine played so insignificant a part in the variation of population. Yet the population hardly maintains its natural rate of increase.

The delta is so favourably situated that we do not expect any deficiency or irregularity of rainfall, which causes famine in the central and western portions of the valley. But all deltas are fluctuating geographical entities. In one portion of the delta the beds of the rivers are gradually raised by the annual deposit of silt, and some rivers are silted up. The banks of the rivers being raised gradually above the surrounding country by the accumulations of silt, swampy depressions arise. Whole areas become waterlodged and sometimes are thrown out of cultivation. The climate becomes unhealthy and a nursery of fever. The natural ripening of the delta produces serious effects on agriculture and health, but these have been intensified by the building of roads, railways and embankments. As a result deterioration is now evident in areas in Nadia, Jessore and Murshidabad, and to a less extent in Howrah and Hughli. The Bhagirathi and the Damodar embankments are largely responsible for the decline of Murshidabad, Nadia and Jessore, and Howrah and Hughli respectively. Instead of the gradual raise of the surrounding region by the natural deposit of silt, only the areas bordering the rivers are being raised owing to successive floods. Thus the *aman* rice cannot grow, since the land is too high for it, yet lack of adequate high land leads to the digging of tanks when house-sites are made. On account of the outward thrust of the population from the

slow and gradual loss of resistance which malaria brings about leads to increased mortality from epidemics and a general lowering of the birth rate. Thus some of the districts in the moribund portion of the delta have already begun to show a decrease of population and also a relative increase of death rate over birth rate. In Eastern Bengal, many districts have now a large margin for an expansion of population. The density of rural population can still increase and the soil can bear the increase easily. But a stage will sooner or later be reached when the growing density will outstrip the capacity of agriculture to feed it.

The following table, which compares the distribution of land in the natural regions of Bengal, clearly shows that population is already pressing heavily on the cultivated area in Eastern Bengal. The percentages of cultivable waste and current fallow in Eastern Bengal are extraordinarily small.

	Percentages of Cultivable Area.		
	Under cultivation.	Waste.	Current Fallow.
East Bengal ..	90	7	
Northern Bengal ..	71	14	5
Western Bengal ..	61	26	12
Central Bengal ..	58	18	24

FERTILITY AND FECUNDITY.—The threat to Eastern Bengal will be more evident if we compare such percentage district by district with the proportions of double-cropped area.

	Percentage of			
	Net Cultivable area to Total Area.	Cultivable Waste to Net-cropped Area.	Double-cropped to Cultivable Area.	Current Fallow to Net-cropped Area.
Faridpur ..	85·7	9·5	14·8	4·0
Bakarganj ..	81·1	11·6	14·7	1·6
Dacca ..	75·3	2·7	20·1	3·9
Mymensingh ..	61·5	11·5	4·1	2·5
Burdwan ..	44·6	24·5	15·5	45·0
Hughli ..	66·5	17·5	2·5	34·9
Nadia ..	35·3	40·4	17·1	54·6
Murshidabad ..	39·6	46·0	15·2	64·6

Of the 8 per cent. of land, cultivable but not cultivated, in Dacca, the most congested district in Eastern Bengal, 4 per cent. is used for growing reeds, bamboos, and thatching grass, leaving only 4 per cent. of the total cultivable area as follow and capable of cultivation. Thus

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1 acre in 25 of land capable of bearing crops is left fallow every year. The actual current fallow in the whole district is only 14 square miles. This implies that a period of 156 years is required before every acre has had a rest from its burden of bearing its one or two annual crops. Considering the extraordinarily small rest given to the land it is suprising to see yet a further effect of the pressure on the soil in the fact that no less than 35 per cent. of the cultivated area is made to bear two or more crops a year.[9]

The agricultural statistics of those districts which show the highest population density in Bengal, Bihar, and the United Provinces respectively, may be compared as follows:—

	Density of population.		Cultivated area to cultivable Area.		Twice-cropped area to cultivated Area.		Gross Cultivated area which is irrigated.		Normal rainfall.	
			PRESENTAGE OF							
	1931	1921	1931	1921	1931	1921	1931	1921	1931	1921
Benares ..	930	898	83·4	82·6	20·3	22·8	26·6	31·1	40	46·4
Muzaffarpur.	969	907	82·2	92	64·8	46	12·5	11·4	45·75	40
Dacca ..	1,265	1,148	94.8	92	18·6	35	..	..	74·3	74·72

The burden of heavy cropping year in and year out for a very dense population can only be borne in Dacca because of the annual flush and inundation by the silt-laden rivers. Yet in a few localities which are remote from the active rivers or situated on old raised land or waterlogged, marks of agricultural deterioration are clearly in evidence. The population here has already started on the path, or is now on the verge, of decline. Indeed, the check on expansion of population began in the area farthest up the alluvial bed of the Padma, and effects are gradually spreading fan-like from this point. The river has succeeded in raising these areas so greatly as to destroy the internal water system, to stop the natural flushing of the area, to leave it waterlogged; and to create on the fringes of the waterlogged area a breeding-ground for malaria. Thus higher mortality from diseases like malaria, cholera and small-pox in these decadent areas is the surest proof of the iniquity of river action, of a crime

(9) Ascoli: Dacca Survey and Settlement Report.

of nature, wihch operates slowly but inevitably in all deltaic tracts. It is considered probable, however, that the next census will show a general decrease in population in the area, though it is unlikely that the decline will spread with any rapidity.' In spite of the elaborate rotation of crops and the cultivation of a heavy-yielding monopoly crop like jute, which the deltaic conditions have encouraged, the pressure of population on the land will similarly be felt elsewhere in Eastern Bengal, if this phenomenal expansion of population continues unabated. Thus the anomalous fact that, while some districts in Eastern Bengal are still increasing their population, others of half the population density have remained stationary or decreased, will slowly disappear; and the higher standard of living of the Eastern Bengal cultivator will decline to that of the under-fed and ill-clothed peasant of Bihar and West Bengal. At a later stage famine will appear—caused not by the fluctuations of rainfall, but by those of the rivers, as in the alluvial plains of China. It is truly paradoxical that man should suffer privation in one of the most wonderfully fertile of valleys; but the paradox is explained by the fact that, where man is improvident, even the most bounteous of natural resources must fail him. To nature's gifts of favourable rainfall and inexhaustible fertility, man must add his own enlightened contributions, such as artificial irrigation and intensive farming, with the cultivation of non-food crops that command a profitable market abroad; but if he neglects or misuses his opportunities he commits crime against his generation, and neither nature's blessings nor his own efforts can avert the consequences. Until the fundamental laws of population are understood and obeyed by the masses, poverty will continue in the midst of plenty, and the struggle for food will continue to bring about the same ecological adjustment as is witnessed in a rigorous and hostile environment.

(10) Ascoli: *Final Settlement Report, Dacca*, p. 35.

CHAPTER X.

LIMITS AND CRITERIA OF POPULATION BALANCE AND OPTIMUM.

STUDIES OF ANIMAL DENSITIES.—Though the study of animal numbers is now in an early stage, yet it throws a flood of light on the conditions of optimum density of human populations. It appears that among various animals there is a certain suitable optimum density which is determined mainly by their size, food habits and other characteristics, and the presence of their usual enemies. Where there are no checks from the limitation of food supply, or from enemies, as in artificial populations studied in the laboratory, there is a certain optimum density which when overstepped leads to a decrease of the span of life. Among certain protozoa it has been found that if there are too few individuals in a culture they do not live so successfully, and this is also said to be true of cells growing in tissue-cultures. Again, it has been found that the minimum density is not the optimum density for an insect population growing in the laboratory. Professor Pearl made out by his work with colonies of fruit flies grown in an experimental universe, certain fundamental principles which have a very important bearing on the growth of human populations.[1] He discovered that there is an optimum density of population of these organisms as regards *length of life*, and that *density actually decreases fecundity*. There is a profound and regular change in the rate of reproduction of these flies, under the conditions of these experiments, with increasing density of population. The number of progeny produced per female per day declines as density increases, at first extremely rapidly, and then more and more slowly at higher densities. After a density of fifty-five flies per one-ounce bottle is passed, the mean duration of life steadily decreases as density of population increases. Another

(1) Pearl: *Biology of Population Growth;* his paper on the subject and criticisms of Haldane, Glover, Netusil, Huxley and others at the World Population Conference, 1927.

way of putting the case is to say that the death-rates in these experiments increased with increasing density of population after density fifty-five had been passed. The figures for mean duration of life are necessarily determined by the values of the death-rates at various ages. Other experiments have demonstrated that, with extremely high densities of population, the mean duration of life (or equally the death-rates) approach an asymptote. In densities below fifty-five, after a relatively small initial rise, there is little change in mean duration of life (or death-rates) with small increases in density. Some other sociological experiments on artificial population, *viz.*, on bacterial populations, were conducted previously by Professor Oscar Bail and gave similar interesting results, to which Nettusil drew the attention of the World Population Conference. Different kinds of bacteria were placed in test tubes in 5cc. of bouillon, and controlled as to the number. They always had an abundance of food. The culture was filtered and placed after certain periods in a fresh bouillon. The control of the fact whether the bacteria were in a state of reproduction was given by addition of bacterio-phage. It was found that the bacterial population grows in number along the logistic surve to a certain stage of saturation of space, where in demographical terms the birth-rate and the death-rate were in equilibrium. This equilibrium lasted for some time, and then there began a decrease of the number of bacteria. This decrease followed the course of the logistic curve, but in the inverse sense. The course of it was about three times longer than the course of the growth; and, finally, the decrease of number was caused, not merely by deaths of already living microbes, but by still higher differences between natality and mortality. The mortality was increasingly higher than natality. Another point is that different microbes needed different amounts of space. With certain microbes the space was saturated by a much lower number than by others, although the differences in the size of their bodies were not remarkable.[2] According

(2) Netusil's remarks in *Proceedings of the World Population Conference*, 1927, pp. 22-48.

to Professor Pearl, the density of population affects the birth-rate. But here we see that the birth-rate, so to speak, is permanently affected after a certain duration of highest density. Also, when the density is afterwards lower and lower, the birth-rate does not grow, but diminishes progressively till it vanishes absolutely. It was found by another investigator that different mutants of drosophila had different abilities as to the concentration which they might attain in a milk-bottle. On the other hand, starvation is found to inhibit the development of the gonads in drosophila. The case of flour-beetles in a standard-sized container would be simpler than that of the drosophila culture, but it illustrates the same principle of competition in limiting the population at the point of saturation. If a culture is started with numbers which represent a super-saturation of the environment, the population dies down to the point of saturation.[3] In the case of the beetles, when the flour which serves as food is renewed the matter of competition is limited largely to competition for space. The adult beetles eat the eggs and keep the population at a stable density. A population thus develops what Chapman calls an internal resistance, even when all other factors of the environment are at the optimum. The theory of stable equilibrium has been treated theoretically by Lotka in his *Elements of Physical Biology*. The changes in the numbers of human and bacterial populations seem to develop in the form of the logistic curve and the life of any population is really limited by some not-yet-known absolute upper asymptote, even when the amount of food remains in abundance.

Analysis of existing data, combined with laboratory experiments upon different insects, demonstrate the great definity of operation of the "space factor"; the existence of an "optimum" density for rate of reproduction and also of a constant relationship which the reproductive rate at any given density bears to the optimum density. Further the optimum density for rate of reproduction is not absolute but can be shifted as the result of changed

(3) Chapman: *Animal Ecology*, p. 154.

environmental conditions which may be physical or organic in character. The factors responsible, at different densities, for the reduction from the maximum reproductive rate have been examined by several entomologists, together with their possible significance in relation to certain phenomena in nature associated with migration and the epidemiology of insect pests. Maclagan places the results on a mathematical basis, in which an empirical formula, used originally by Farr, has been adapted to describe the relation between population density and rate of reproduction.[4] Pearl's explanation of the phenomenon as being the result of adverse effects upon the reproductive system, induced by factors which must be termed in the present state of our knowledge as psychological, holds the ground among entomologists. The so-called psychological effect almost certainly results from the repeated stimulation of excessively numerous physical contacts. Confirmatory evidence of such an adverse effect is derived from a consideration of Bliske's work on the effect of crowding upon the growth rate of tadpoles, which he found to be a function of the group stimulation possibilities. That contacts do play an important part in the lives of the lower animals is supported by Wheeler's belief that the ants' world is largely one of contact-odour shapes. Maclagan concludes: "It would appear that natural populations automatically check their own increase by virtue of this density effect, and that the organism itself imposes the ultimate limit to its own abundance when all other factors (biotic and physical) normally inhibiting population increase have failed." In the case of flour beetles maintained in environments of known size it was found that although thousands of eggs were laid daily, the density of individuals remained almost constant. The adult beetles ate the immature stages in proportion to the concentration of individuals. Thus the balance of numbers of organisms in nature is maintained.[5] There also appear to be definite physio-

(4) Proceedings of the Royal Society (B), CXI, No. 773, 1932.

(5) Chapman: The Quantitative Analysis of Environmental Factors, Ecology, April 1928.

logical limitations of life span not explainable in terms of limits induced by unfavourable climatic or seasonal states. Cleave found a typical instance of a life span limited by hereditary physiological control in the large branchifernous snail. Among this species the females live approximately three years though the males usually exceed an age of one year by not more than a few weeks. Limitation of individual life span and especially the differential between the maximum age attainable by males and by females in this species produce seasonal facies to the population that could not exist in species having indefinite duration of life or having identical longevity of both sexes.[6]

Elton dealing with the regulation of numbers of individuals in populations in nature gives the impression that conditions external to the organism establish the chief checks limiting numbers. Climatic factors, relations in food chains and epidemics are often more strongly emphasised by some animal ecologists than rate of reproduction, change in habits, length of life span and other factors determined either by heredity or by physiological processes of the individual.

NATURAL LIMITS TO ANIMAL NUMBERS.—In normal wild nature, however, we can, hardly expect to see the type of check to numbers found in an experimental universe. Even in the fruit flies, though the population is stablished by a fall in fertility with density which is more important than the rise in the death-rate, the stable density is three to five times greater than the optimum density as judged by the length of life, which is as good a criterion as one can get. Most animals are more numerous than is usually supposed but the enormous power of multiplication of animals is not given full rein because each animal tends to have a certain suitable optimum, which is determined mainly by the size, foodhabits and special adaptations of each species and this applies both to herbivores and carnivores. Competition for food among individuals of

(6) Cleave: Length of Life Span as a Factor in Regulating Populations. Ecology, January 1934.

the same species, which need and strive for almost the same things keeps numbers at an average abundance. Species within a genus arc however usually protected more or less from competition by differences in habits. Again, if an animal can attain new ways of living, it may be able to invade habitats where there are no competitors. Pearse quotes Vestal who has summarised the characteristics that may remove animals from competition as (1) structural (the fossovial fore-limbs of the mole enable it to live underground); (2) physiological (the clothes moth lives on keratin, which is indigestible for most animals); (3) psychological (one mouse prefers to live in the forest, another in the meadow); (4) biographical (the butterfly hunts by day, the moth at night); (5) numerical (two species that use practically the same resources cannot be as numerous as if there was only one).[7] Each species of animals thus tends to approach a certain desirable density, which is maintained by a series of adaptations extending beyond the life of the species and touch the lives of other animals. Such adaptations are different in different species and in different ecological areas, maintaining an average abundance for all species of animals and a stable equilibrium of the entire regional complex including both plant and animal communities. Among wild populations of small rodents and other animals, mainly mammals and birds, the work of Elton has shown that both disease and the limitation of food-supply determine for each species a certain optimum density which is neither too low nor too high and is not the same at different times or in different ecological areas. Before actual starvation keeps down the numbers, enemies control them, while epidemic diseases appear as new checks, striking a sort of balance of the numbers with the surroundings. Herbivorous animals, such as the deer and antelope, which cover miles and miles of territory in South Africa depend on their usual enemies to preserve their optimum numbers and to prevent them from over-eating their food-supply. On the other hand, the absence

(7) Pearse: *Animal Ecology*, p. 96.

of enemies weakens the animal populations and diminishes their environmental resistance thereby proving the existence of enemies to be a biological necessity to the species. Thus as Julian S. Huxley observes: "To have the right enemies, though it can hardly be spoken of as an adaptation, is at least seen to be a biological advantage." Since the carnivores do not confine themselves to one kind of food, there is neither too much nor too little destruction of their prey. The goshawk in Canada preys alternately on grouse and hare, and the red fox on mice and hare, according to their relative abundance.[8] Periodic outbreaks of disease seem also to carry off large numbers of such animals, and bring down the population to an equilibrium point. Serious plagues of mice, rats and other rodents are found to occur from time to time in various parts of the world, when their numbers outrun the check imposed by their enemies. It is then that an epidemic appears and kills the rodent populations, bringing down the number even below the mean. Rabbits, hares, lemmings, and other animals, undergo regular and violent fluctuations in numbers from year to year, which Elton has analysed into three main processes: first of all, the epidemic which kills them off when a certain density of population is reached; secondly, the natural tendency to increase, which leads to recovery of their numbers after the epidemic; and, thirdly, the climatic influences which speed up the rate of reduction in certain years. Haldane refers to Mckendrick, who also finds that many animals, as soon as they overstep a suitable density, fall victims to malignant epidemics which normally would not be a scourge. The increase in numbers following from a breakaway from control by natural enemies in sometimes partly relieved by migration. But migration, as Elton observes, usually implies concentration of the animals into swarms or flocks and so favours the generation of epidemics and also makes it more likely that enemies will kill more of them. During the lemming years in Norway, the migrating animals are

(8) Elton: *Animal Ecology*, p. 123.

eaten by all manner of unusual enemies including reindeer, trout in lakes and cod out at sea.[9] Forbes made an investigation of the food of birds in environments which were normal as to their populations and also in an orchard where there was an outbreak of insects. It was found that birds acting as predators tend to keep the numbers of insects from increasing above their normal concentration by *feeding on the most abundant forms,* and even increasing the per cent. of insects in their food.[10] He observes: "Whatever power the birds of the vicinity possessed as checks upon destructive irruptions of insect life was being largely exerted here to restore the broken balance of organic nature". The coloration of male birds by inviting their predaceous enemies seems to have an effect upon establishing a numerical balance. Mottram advances the view that male birds are often brighter coloured than females because they are of less value to the race. They may be destroyed after they have exercised their fertilising functions without endangering the survival of the young. He believes that their loss through the attacks of their enemies serves to a certain degree to protect the females, because enemies are thus kept more or less in a condition of satisfaction in regard to their food requirements.[11]

TERRITORIAL HABITS IN THE ANIMAL KINGDOM.—It also appears that birds, as well as carnivorous and herbivorous animals, assume ownership of territories each occupied by one or more families or individuals. Such division into territories, which is connected with courtship or nesting and other habits of the species in question, indirectly limits numbers. Where the animals have fewer enemies the territorial system seems to be a convenient means of regulating numbers. The fact that herbivores are more numerous than carnivores makes it possible for the latter at a certain point in their series to limit their

(9) Elton's Article on Animal Ecology, Encyclopædia Britannica, 14th edition.

(10) See Chapman's Animal Ecology, Typescript edition, p. 156; also Folsom: Entomology, p. 244.

(11) Mottram: *Controlled Natural Selection and Value Marking,* quoted in Pearse's *Animal Ecology.*

numbers by dividing their country and therefore the available food-supply.[12] It must be emphasized that both among certain birds and among carnivores the territorial systems are not always meant to divide only the food-supply in a suitable way. They are connected with a chain of habits relating to courtship, nesting, watering, etc., which represent certain psychological factors controlling the numbers. The pair of birds or carnivores occupies a certain area round the nest. In these cases there is an equilibrium density, not owing to the direct pressure of food-supply, but to the operation of the instinct to defend the area round the nest. What happens in the case of birds is that the male birds arrive first and fight among themselves for territory. These are then followed by the females, each one of which becomes attached to one male occupying a well-defined parcel of land, or preserve, or a certain tree and the ground about it. The work of Howard shows that the birds' pugnacious instinct bears a direct relation to the occupation of a territory which is serviceable in that it provides an adequate supply of food in the vicinity of the nest and thus obviates the necessity of the parents being absent from the young for long. The desire for territory is keenest in the first phase when the male bird seeks the female, and wanes during the phase of nest-building and egg-laying. There is a linking of the pattern of reactions and the selected territory, which indeed governs every phase of the bird's behaviour. When reproduction and the rearing of broods are ended, the gregarious instinct becomes dominant, and parents and offspring and other companions seek again their former haunts. The struggle for territory then begins anew. A certain number of young birds cannot breed at all on account of the lack of adequate breeding places in a crowded forest, or they migrate *en masse*, forming new centres of distribution, where the process will repeat itself and from which expansion will proceed afresh. In most bird species every pair thus lays exclusive claim at least to its own nest and often to a certain radius round it as

(12) See Elton: *Animal Ecology*, pp. 122-26; also Howard: *Territory in Bird Life*.

well. This domain may be either a bush, a piece of ground, a swamp, a small pond, or part of a stream; the last applies to moorhens, coots, swans and others. Thus with many species of birds sociability is at its lowest ebb during the breeding season, when the flocks or parties break up and settle in pairs, dispersed over the country. But with others particularly sea-birds, as Nicholson points out, the reverse holds good; their scattered numbers rally from all directions to peculiar points where they breed in massed colonies often so dense that they hardly leave room to tread. "These (differences) are not simply manifestations of a communist or an individualist temperament; they are solutions of the economic problem which in one form or another every species has to meet." There is among birds a striking relation between the availability of food for the young and the size of the nesting area. Birds like plovers, that have difficulty in securing sufficient food for their young defend large nesting areas whereas certain sea-birds like penguins and gulls that have no difficulty in securing an abundance of fish from the neighbouring ocean, crowd so close together that they have barely room to sit on their eggs.[13] The cause of this congregation is to be found in the lavish prodigality with which nature has provided food. Seebohm, for instance, describes this in his Siberia in Europe. "Seed-eating or fruit-eating birds find an immediate and abundant supply of cranberries, crowberries, and other ground fruit, which have remained frozen throughout the winter, and are accessible the moment the snow has melted, while insect-eating birds have only to open their mouths to fill them with mosquitoes." In a penguin colony each rectangle, bounded by pathways, belongs to the pair owning the nest built thereon. On the other hand, many birds of prey lay claim to the same domain throughout the year, that is to say, beyond the brooding period, and suffer no rival within their boundaries.[14] Finches live in large mixed flocks in winter but

(13) *Animal Ecology*, p. 67.

(14) Alverdes: *Social Life in the Animal World*, pp. 160-61.

during the breeding season when they have to rear their young with a large supply of small insects they are found everywhere in pairs, occupying compact territories from which all others of their kind are jealously excluded. The rooks which work in company and often combine together to repulse enemies, differ, however, in maintaining the community in tact in the breeding season, many nests being built on a single tree or in adjoining ones.

THE TERRITORIAL DIVISION OF FOOD-SUPPLY, AN ELASTIC SYSTEM.—Thus territory or the distribution of the bird population at various seasons differs according to the habits of the birds, the amount of food available in the breeding and other seasons and the periodic demand for nesting sites. Territory has to be understood, concludes Nicholson, not as a rigid system of partition into small areas, each occupied by a jealous pair but as a delicately adjusted balance created and maintained by economic pressure and varying greatly in its details from time to time and from place to place according as the pressure varies.[15]

Similarly, the Indian tiger or the African lion appears to divide forests according to definite territories in which one pair or family of these animals lives. It preys on the herbivores within its jurisdiction and resents any encroachment of other carnivores. The relationship between the carnivores and their prey is stabilised within a margin of safety. This is due partly to the fact that an increased toll leads to increased wariness and more difficult hunting but above all to the territorial system, which operates to safeguard the standard of living. Nicholson has shown that in the case of the falcon its native fierceness ceases to be so readily stimulated when an increasing abundance of prey relaxes the struggle for existence. In a similar manner under conditions of abundant food-supply for the carnivores a point may be reached, where territory is no longer strictly held by the tiger or the lion, and a tolerant individualism may supervene, several pairs foraging over

(15) E. M. Nicholson, How Birds Live; article on Birds, Reproductive Habits, in the Encyclopædia Britannica, 14th edition.

the same forest without serious friction, and even breeding side by side where suitable sites exist with convenient access to food. Elton observes: "We know practically nothing about the way in which such animals settle the size of their territory, and little enough about the extent to which the territorial system is found among mammals at all. There are indications that some herbivorous mammals limit their numbers to some extent in this way."[16] Elephants, wild buffaloes and antelopes in particular divide large forest areas according to territories in which certain families or herds graze and other herds would not come near. Richenow describes how every horde of gorillas or chimpanzees inhabits a perfectly well-defined and limited area, whose size is regulated according to the number of animals in the horde. For a horde of average size its diameter measures about 15 kilometres; the domain of an old male, living alone, is correspondingly smaller, these recluses in particular defending their areas obstinately against every intruder. Similarly every horde of apes possesses, as a rule, a clearly defined domain whose extent varies in different species. If two hordes encounter one another fierce fighting may ensue. Alverdes has given some further instances. Each herd of kangaroos possesses its own grazing place; sometimes it possesses several, linked together by well-trodden paths. Herds of North American, prong-horned antelopes each inhabit a definite tract of country within which they travel long distances. Every ant-state has a special hunting ground, and if an ant belonging to one state trespasses on the territory of another a battle follows, the result of which is usually the retreat of one of the parties; it very seldom happens that two neighbouring states become used to and tolerate each other.[17] It also appears that bees, ants and termites, beavers, rabbits, prairie dogs and marmots, which live in great aggregations, have some system of spacing out their colonies so as to prevent congestion. When these exceed suitable density, they migrate and find new hives, nests and colonies. Mitchell describes a fine colony of prairie

(16) Elton: *Animal Ecology*, p 125

(17) Alverdes: *Social Life in the Animal World*, pp 160 162.

dogs living on a private estate in Sussex. Recently a number of them, for no obvious reason, since there was plenty of room and plenty of food, moved off more than a mile, crossing very irregular ground and settled down in another field.[18] The beavers though gregarious and co-operative live in isolated colonies in their ponds. When their numbers exceed an average density, the surplus population migrates in quest of new settlements, where they may find enough trees to fell for food, making lodges, dams, etc. Some observers say that the flitting is on the part of the grandfathers and grandmothers, the old and the bold.[19] Thus there can never be a dense continuous beaver population over a large area. The beaver population is never subject to the wild and rapid fluctuations that beset other rodents but is regulated within much narrower limits, there being less wastage of lives.[20] No doubt feeding, nesting and storage habits have played an important part in bringing an easy adjustment of numbers in a beaver lodge and village to the ecological area.

ECOLOGY OF ANIMAL OR HUMAN CELEBACY.—A very interesting mode of adjustment of population to food shortage is seen among the kangaroo-rats of the American semi-deserts. On account of the sparseness of vegetation, the kangaroo-rat has a rigid territorial system, and lives a curious bachelor or spinster life in which adults visit each other for sexual intercourse. Either a solitary male or female or a mother with her family is found in each mound. If a couple were to live there instead of one the supply territory would have to be uneconomically large, the animal's journeys in search of food unprofitably long.[21] Much in the same manner unfavourable economic conditions have originated monkhood and perpetuated polyandry as the form of marriage in the bleak plateau of Tibet where the labour of one person cannot support the household and yet at the same time the sex desires have to be

(18) *The Childhood of Animals*, p. 178.

(19) Thomson: *The New Natural History*, p. 82.

(20) The Science of Life by H. G. Wells, Julian Huxley and G. P. Wells, p. 672.

(21) *Ibid.*, p. 600.

satisfied. Among many primitive peoples group marriage has survived simply because of its economic advantage in preventing the separation of brothers and the formation of independent households. Thus among men, among the specialised social insects as well as among the isolated carnivores and herds of herbivores and even among some rodents we find a sort of preference, sometimes physiological and sometimes psychological, to avoid undesirable density whether in the individual nest or home or in the colony.

INSECTS AND POPULATION CONTROL.—There are several characteristic methods to which the higher social insects resort in order to overcome the danger of their populations outstripping the food-supply. First, they rigidly restrict reproduction, excepting when food happens to be unusually abundant, to a few individuals, suppressing it in all others. This secures that the fecundity of certain females, the queens, and of the males, the drones, becomes greatly enhanced or hypertrophied, while the remaining females or workers are reduced to physiological sterility. With the social wasps and bees, the difference between the queen and a neuter which devotes itself exclusively to the work of the colony depends solely upon nutrition. Sterility is the result of what is called alimentary and nutrical castration. Nutrical castration (derived from *nutrix,* a nurse) takes the place in the adult worker of the alimentary castration to which it was subjected during its larval period. Bouvier observes: "Just as bees in their hives obtain queen larvae at will by feeding the very young worker larvae with the royal jelly, the workers of social Hymenoptera may become fertile by feeding on the food intended for the brood, and in all cases, excepting perhaps with the ants, the fecund workers lay exclusively male eggs.[22] In many cases the castration of the workers comes from deficiency of protein in larval food, while the difference between worker and soldier depends upon difference in the amount rather than the quality of food. With termites also the castration is of alimentary origin,

(22) Bouvier: *The Psychic Life of Insects,* p. 290 91 and 340.

for their young larvae can also be made royal when they are better nourished. All the forms of termites are alike at birth, except as regards sex, and the difference between worker and soldier depends upon the character and amount of the food.[23] Some biologists, however, think that the difference between worker and soldier in termites, is qualitative and cannot be explained by mere nourishment as in ants, but is to be attributed to some elaborate hereditary machinery. In the case of ants the profounder morphological differences, which separate the queens, soldiers and workers, cannot be attributed to differences in larval feeding or internal secretions. Wheeler thinks that such differences were originally ontogenetic and determined by feeding, as they still are in the social wasps and bees, but that in the ants the germ plasm has somehow been reached and modified, so that an heredity basis for caste differentiation has been established. The production of pseudogynes in ant colonies, inhabited by the coleopterous symphile Lomechusa, also show that nutrition and metabolism are closely concerned with sex and its expression. According to the same authority "These queer, mongrel forms are an abortive combination of the female thorax with the stature, gaster and head of the worker. Wasmann has also suggested what seems to be the more probable explanation that the pseudogynes may arise from the female larvae that have been merely neglected and left unfed after they have passed the stage at which such treatment would lead to the formation of workers". George Salt shows that effect of stylopization in bees is to cause an upset in the nutritional balance of the host which affects the reaction of the sexual hormones and produces intersexes.[24] Secondly, it appears that the females of the wasps, bees and ants, which are provided with a smaller muscular sac filled with sperm, during a single act of mating can control the sex of their offspring by permitting or disallowing sperm to leave the sac and fertilise the eggs. When the colony becomes too small

(23) Grassi quoted in Folson: *Entomology*.

(24) Journal of Experimental Zoology. For a careful study of the effects of food or caste differentiation among the social insects, see Wheeler: *Social Insects*, p. 192ff.

these insects can thus produce the missing sex and thus increase numbers. On the other hand, the reduction of the male to a mere episode in the life of the female contributes towards a stable density. The colonies of ant, bee and wasp depend on the labour of sex-less females. A large population of useless males will be a burden to the colony. Thus a fertile female or a royal couple are given the reproductive functions, and the proportion of the sexes and even the function of the neuters can be varied according to the needs of the colony. Indeed, matriarchy or gynarchy, rigid control and economy of reproduction and communism seem to go together among the higher social insects. Thirdly, even under such rigid economy of production, if the number of reproductive males or drones outstrips the food-supply, these are expelled by force, as in the hive-bee community. Sometimes again, though rarely, there is a massacre of the drones. Fourthly, there is the phenomenon of swarming which, as Wheeler observes, occurs as a rule when the environment is unfavourable or the colony has grown to such dimensions as to outrun its food supply, so that emigration of portions of its population becomes imperative. Besides lack of food-supply, lack of empty combs for egg-laying and honey-storing, lack of sufficient ventilation in the hive or an over-production of drones or some other cause of discomfort induce the feverish excitement known as the swarming fever. The swarming bees accompanied by their queen rush out and whirl in the air until they find a suitable lodging. Some workers remain behind in the old colony where a new queen takes the place of the old. The swarming from a well-peopled hive or nest thus results from the marvellous reproductive capacity of the queen-wasps, queen-bees and queen-ants and queen-termites, though Kellogg points out that it is immediately an instance of photo-tropism. Many of the tropical wasps form large perennial colonies, which from time to time send off swarms consisting of numerous fecundated females or of one such female accompanied by workers, to found new colonies. Similarly the queen-bees disperse after mating with the males and form new colonies by

swarming. Among the tropical and extra-tropical ants, when the formicary contains too many males and queens, the fertile forms from all the nests of the same species over a wide expanse of country escape simultaneously into the air and celebrate their marriage flight. This flight provides not only for the mating of the sexes but also for the dissemination of the species, since the daughter-queens, on descending to the ground, usually establish their nests with detachments of workers at some distance from the parental colony. It appears that winged forms do not appear in nests of the carpenter ant until colonies are two years old and until about 2000 workers are present.[25] Among the termites when the king and queen are present in the nest substitute forms do not lay eggs but if they are removed the substitutes mature. But when the termitary is overcrowded there are flights in which millions of these creatures participate. These are followed by the formation of a number of new colonies founded by the female, with the assistance of the workers and soldiers. It is in this manner that new hives, formicaries, and termitaries are established, relieving the congestion in the parental settlements. It is of course true at the same time that the ant-colony and the termitary offer annually a tremendous sacrifice of myriads of these creatures; but their marriage festival is preliminary to dispersal of populations when these grow too large, and contributes to the multiplication of their numbers under better conditions of food-supply[1]

'SWARM PHASE" OF GRASSHOPPERS.—That overcrowding causes some insects to assume certain habits and biological characters which differ strikingly from the normal is also brought out by recent studies of locusts and grasshoppers. The work of Uvarov shows that the gregarious locust and the solitary grasshopper represent one and the same species in different phases of its existence. Overcrowding, for some totally unknown reason or reasons, causes a species to assume the "swarm

(25) See Pears: *Animal Ecology*, p. 71.

(1) Wheeler: *Social Life among the Insects*, pp. 13, 88 and 162; Maeterlinck: *The Life of the White Ant*, pp. 109-111.

phase" characteristics, with the distinct coloration, structure of the penotun gregarious instincts, and so on. When the swarm becomes thinned out by disease and natural enemies, the survivors tend to separate and to assume the characters of the solitary phase. With the return of favourable conditions, these solitary individuals breed up again rapidly, the gregarious instinct begins to reassert itself, and the "swarm phase" is repeated, possibly after an interval of several years. This indicates a rhythm of growth of these insects which is associated with favourable conditions. When their numbers exceed a certain density they become gregarious and migrate *en masse* to assume different biological characters in other localities.

ANIMAL DISPERSALS AND MIGRATIONS.—The migrations of locusts may also be compared with the large scale migrations of herbivorous mammals in search of pastures, or fish in search of their spawning grounds, or birds undertaking long and arduous journeys in large flocks in search of breeding places. The pressure of population is the cause of migrations in the case of locusts, hares, rats, lemmings, squirrels, prairie-dogs, sand-grouse and aphides when they suddenly depart in swarms for new lands. In many cases, as in herds of wild cattle, asses, deer, gazelles and antelopes, there is a periodic mass movement or migration from summer to winter quarters and back again, and the team work is on a higher level than the occasional trekking of large numbers of rats, rabbits or lemmings. Thomson classifies animal migrations into three kinds (*a*) true migrations, bound up with weather, with food-supply and with the birth of the young as in birds, fur-seals, marine turtles and salmon, (*b*) regular big movements which occur in connection with seasonal changes, as in the cases of wild asses in the steppes and uplands of Asia, and antelopes, gazelles and other herbivores in South Africa, (*c*) irregular wanderings due to a flood in the river of life; that is, to an enormous increase in the number of mouths to be filled, as in the case of locusts and the small rodents, which all have big appetites and multiply very rapidly.[2]

(2) See Thompson: *The New Natural History*, Chap. XII, pp. 75-77, and Chap. XVII, pp. 138-146.

The methods employed by animals to escape from an overcrowded population, or to find a proper habitat when they migrate or become dispersed, have been described by Elton, and these throw light on the trekking of primitive tribes or the wanderings of more organised peoples.

On the other hand, among stay-at-home populations such as the bees, wasps and ants, the trains or patterns of behaviour connected with feeding, oviposition, making, closing and opening of the nest which directly or indirectly maintain a numerical balance in the nest, colony or settlement are much more elaborate and complex than we find in any other gregarious community including man.

LESSONS FROM NATURE IN POPULATION CONTROL.—Man may learn much from the methods of control of population in insect societies. It is not possible that sex and reproductive function may be controlled in human society through the regulation of food acting indirectly, as among bees and termites. But, if nutrical and alimentary castration is impossible and a neuter caste cannot be produced in man, the intensity of sex desires as well as fecundity may perhaps be controlled in some measure through a particular kind of nutrition. Secondly, if under certain circumstances women do not bear children or are sterile, they may rear the offspring of others much as is done by worker ants and bees, which are undeveloped females, and thus satisfy their philo-progenetive impulses.

In our ascent in the scale of evolution it is the psychological factors which gradually play a more dominant part in the regulation of numbers. In the communities of wasps, bees, ants, and termites the limitation of families and the provision for the young which are chiefly economic in character, are brought about by the operation of a complex chain of instincts and through the development of castes. The latter is probably influenced, as we have seen, by starvation or a particular kind of nutrition. Both among birds and the terminal animals which are either at or near the end of food-chains, and consequently have fewer enemies (leaving aside parasites), the division of country into territories is common. A chain of instincts

and habits connected with defence, nesting, courtship and breeding indirectly limits their numbers. At the same time animals at the end of food chains control their numbers by a slower rate of breeding. Some do not even propagate at all. Elton gives instances of the snowy owls, skuas, and lemmings which in certain years, when food is scarcer than usual do not breed. In years of scarcity the skuas and probably the snowy owls make no attempt at nesting. Their systems probably respond automatically to low temperature and lack of food, their ductless glands are not set in the direction needed if the ovaries are to pile up yolk in their eggs and the reproductive impulse is never felt.[3] Some animals which, apparently have been successful in the efforts to continue to live, are never abundant, *e.g.*, the osprey.[4] There is a species of desert mouse which has only two young per year, that is to say, probably very few more than would be necessary to replace deaths in the population caused by old age or accident. The reproduction of the carnivores is adjusted to so low a rate that their numbers always remain small and there is hardly any danger of overstepping the limits of food supply. Indeed, in the mammals the maintenance of the species by the production of enormous families has ceased. Mitchell remarks: "Some of the little rodents may breed several times in the course of the year and produce large litters, and there are some fecund mammals, such as pigs, where the litter may contain a dozen or even more. But these are rare exceptions. In the vast majority of cases, mammals breed no more than once a year, and in some instances only once in every two or three years. The usual numbers are one, two, or three at a birth, and the higher in the scale of mammalian life one looks the smaller is the number that is usual." Parental affection is very strong amongst many mammals, and often there is real training of the young by their parents. In quite a large number of cases the fathers of the mammals take some part of the burden of bringing up and

(3) *The Science of Life*. By Jullian Huxley, H. G. Wells, and G. P. Wells, p. 606.
(4) Pearse: *Animal Ecology*, p. 96.

educating the family. The prolongation of the period of youth and the close association between the different members of the family gradually develop intelligence and affection until we reach man, among whom the reduction of families and parental care has reached its highest phase. In man both spatial and social psychological factors limit numbers, but the artificial conditions of food, shelter and clothing have superseded periodicity in sex life, made the mature period longer, and diminished the importance of the natural check of numbers in the low rate of reproduction. Even the highest species of animals are quite exhausted after the satisfaction of sex, and it is this which explains why in the case of most animals long rest periods are necessary, and sexual excitement and activity manifest themselves in a new rutting period only after a considerable interval. Then sexual life emerges with overwhelming force, but does not last long, and the whole species sinks into sexual apathy once more. Rutgers shows how in domesticated animals, as well as in the anthropoid apes, the gorilla, chimpanzee and orang-outang in the Zoological Gardens, phenomena analogous to menstruation are observed periodically every three or four weeks. The females of domestic animals show more frequent copulation and pregnancy, while the males are always libidinous and ready to cover, not merely at the rutting periods.[5] In the wild state such animals will not be sexually active throughout the year. Most of the animals mate only once or twice a year, while many cannot breed at every heat period. In monkeys special sexual seasons are experienced at definite times of the year, when breeding takes place. It is suggested that ovulation is limited to this special season, and that, although copulation may take place at other seasons of the year, conception can only follow copulation at this special season. According to Boas the permanence of the female breast, anomalies in sexual behaviour and the lack of a mating season are among the traits of man's domestication. Carr-Saunders observes: "In civilised man, so far as is known, ovulation

(5) Rutgers: *The Sexual Life*, Part IV, pp. 277-280.

is never confined to any particular season of the year; conception can, therefore, follow copulation at any period. But we do find evidence of the former existence in man of a special sexual season, and this is of particular interest because it suggests that at one time there was in man, as there usually is in monkeys, one season only during which conception could follow copulation."

SEX PERIODICITY AND POPULATION.—It is clear from evidence that primitive tribes had, or still have, their rutting seasons as regularly as the deer, the antelope, the dog, the wolf, or any other animal.[6] Many of the aboriginal tribes of India, which now follow the peaceful vocation of agriculture, have still their annual spring and autumn festivals, when there is a large concourse of youths of both sexes, and these are followed immediately by betrothals and marriages. We here find reminiscences of the rutting period in primitive human society, occurring twice in the year. Even in modern society, there are often observed seasonal fluctuations of births due in part to physiological changes in summer, spring, and winter. Investigators have found the number of births in Europe higher in February and March, and, again, in September and October than at other seasons. The Esquimaux are said to have a more definite season of child birth than any other race.[7] Domestication of wild animals has led to the extension of the sexual season and increase of the numbers at a birth. This is attributed to stable and adequate supply of food, protection against the inclemencies of the season, and also to selection. Heape observes: "It would seem highly probable that the reproductive power of man has increased with civilisation, precisely as it may be increased in the lower animals by domestication, that the effect of a regular supply of good food, together with all the other stimulating factors available and exercised in modern civilised communities, has resulted in such great activity of the generative organs, and so great an increase in the supply of the reproductive elements that conception in the

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(6) See Carr-Saunders: *The Population Problem*, Chap. V.

(7) Baker: *Sex in Man and Animals*, p. 145.

healthy human female may be said to be possible almost any time during the reproductive period." With advance of civilisation man's rutting season is thus entirely superseded by a regularity of sex impulses and their satisfaction. The frequency of his sexual act may be very high at all times, sexual excitability being almost constantly present, while procreation is possible at any time in the sexual cycle. It is clear that from a biological point of view man is sexually aberrant in that in him alone mating has become an end in itself and is vastly in excess of the needs of procreation. It was caused or exaggerated by three very important facts which have thus been summarised by Stanley Hall, (1) the development of the hand and its possible misuse; (2) the erect position, which made impregnation less certain and (3) the use of clothing and fire, and the security of food and shelter, which made an instinct that had been seasonal active throughout the year.[8] These peculiarities of man are mostly responsible for the problem of overpopulation. Amongst less advanced peoples and the lower strata of a civilised society not merely is there a high rate of reproduction, but even the social—psychological causes also hardly operate as a check to numbers, so that the danger of over-running the food-supply is much greater than in the case of many animals which control their numbers in diverse ways. In animals the development of secondary sex qualities such as display, nesting or ornamentation for allurement subserve the purpose of binding the male and the female in concord throughout the mating and breeding season and the male must win his female anew at every approach. In man courtship has often become formal and conventional, and the human female succumbs to sudden passion of his mate without the full arousal of those higher secondary sex qualities, which insures less frequent impregnation as well as the full benefit of heredity for the offspring in the case of animals. Moreover puberty in advanced society begins earlier, while reproduction is continued an advanced age. In India, for instance, girls attain puberty between

(8) Stanley Hall: *Morale*, p. 258.

12 and 15 years, and reproduction has not been unusual at 13. Lastly, the period of lactation is reduced and there are shorter intervals between births among advanced than among backward peoples. On account of the lessened responsibility of the female parent for the maintenance of the mother and her child, there has been a closer association between the sexes within the family group, and the natural check against frequent reproduction has been removed. Johanna Elherskirchen has held that modern civilisation has robbed women of their racial contribution. Formerly she of necessity had to care for herself and child; now this task has devolved upon man. As a result women have become sexually passive. Sex-relations with primitive women, on the other hand, were active but infrequent—a periodicity of twice yearly being maintained. Only by freedom from sex relations over long periods of time will woman regain her satisfaction in them.[9] Yet in more advanced communities, and in the same community among the higher social strata, both social and psychological factors play a larger part in controlling and reducing fecundity than in backward communities and social groups. It is thus that we may to some extent measure the rise in the scale of evolution of species of animals, and of human communities and groups, by low fecundity and the ability to control reproduction, which indirectly ensure a high average expectation of life. It appears that man's control of the food supply, its variety, richness, certainty, and regularity, as well as general improvement of the conditions of life, which have minimised the dangers to which the young are exposed, have not only increased fecundity, but also have destroyed the natural checks to the increase of numbers by the high development of the parental and gregarious impulses, the prolonged state of infancy, and a more or less successful protection of the mother and the child. Herbert Spencer has laid down the general principle that the perpetuation of the species is achieved with the least sacrifice of parents in the highest form of the family.

(9) *Social Science Abstracts*, No. 1496, April 2, 1929.

The absence of a natural limit of fecundity as civilisation has progressed has demanded, on the whole, great sacrifices from parents. On the other hand, the lack of restraint, stressed by the drab and dreary routine of life among the majority of the workers as well as by positive sex stimulation, coupled with the extension of the reproductive period, is now a serious problem in social biology. The period preceding reproduction and between births is shortened; while the increase in the number of offspring has meant serious physical suffering and denial of the pleasure of rearing healthy children. Lastly, there are fewer years left for the mothers following the cessation of reproduction. Generally speaking, not merely is fecundity lower in the higher economic and social strata compared with the lower layers of the population, but the former also show greater longevity and lower infant mortality. According to Casper, the following numbers out of 1,000 princes and 1,000 poor survive the given ages. "With still greater reason this may be said of the longevity of prominent men, generally, compared with that of the common people."

Ages-Years.	Princes.	Poor.
5	943	655
10	938	598
50	557	338
80	57	21

(and so on).[10]

Sorokin, who has made a careful study of the fundamental differences of the lower and higher classes, concludes that the higher social classes are stronger physically, and also healthier, and have greater vitality, than the lower. The duration of life of the higher social strata is longer and their mortality rate is less than that of the lower social layers. The health of the higher classes is better than that of the lower. On the average, the higher social classes are superior physically to the lower classes. These facts show that the social stratification is positively correlated with the stratification of the same population from the standpoint of health, strength and physical superiority. This correlation seems

(10) Sorokin: *Social Mobility.*

to be permanent; it has existed in the most different societies of the most different times, with the exception of the periods of decay of the aristocracy or of the whole society.

HIGHEST EXPECTATION OF LIFE, THE TEST OF OPTIMUM DENSITY.—We have seen that in artificial populations of flies and bacteria the mean duration of life tends to diminish progressively as a certain optimum density is exceeded. Both human and bacterial populations seem to grow in the form of the general logistic curve and it appears that it is the highest average expectation of life from which we should judge the optimum density.

In the case of animals both optimum density as well as mean duration of life have been determined from without, by natural selection in the course of the struggle for existence. Pearl suggests that the duration of an animal's life stands in reverse relation to the amount of its metabolic activity. In the case of the social insects the life-span would seem to be roughly proportional to their respective expenditures of energy. According to Wheeler, both the lengthening of adult life and the fecundity of the ants, termites and social bees have been gradually acquired in response to the very restricted environment in which they not only develop but also continue to live as adults. No doubt no mere lengthening of infancy and childhood would be of value to the animal without a preceding or concomitant lengthening of the adult life of the individual. It is obvious that the social *milieu* or co-operation between different members of the social species contributes a great deal towards both these objects. On the other hand, if the size of the association or colony exceeds a certain average density, the conditions of living become unfavourable and the life-span is reduced, the infants and mothers in particular having shortened lives.

In man the operation of these limits depends upon various social-psychological factors and means of social control. In less advanced societies, such factors are, however, not insistent enough to regulate numbers. Thus

population gradually expands, though not up to the extreme limit of food-supply. As in the case of animals and insects human numbers are not directly brought down by actual starvation or famine, but though the indirect operation of the forces of natality and mortality. There is a lowering of vitality, with consequent decline of survival rate and predisposition to epidemics, and thus the population is maintained at an equilibrium density which is something very different from optimum density, for there is great waste of life and the average expectation remains low. In advanced and well-organised societies, the agencies of social control effectively keep down numbers as well as the death-rate, resulting in better economy of reproduction and higher physiological well-being. The physiological waste is reduced and there is far better adaptation with fewer births and prolonged maturity and decreased mortality. Thus the population optimum is to be judged from the highest average expectation of life. It implies not merely economy of reproduction which is the physical basis of social progress but also the highest economic productivity. Longevity is usually associated with high productivity, good morals, enlightenment and social peace. Thus a society which has the highest average expectation of life may be regarded as the soundest, biologically and socially. And this standard may be adopted as the best working criterion of an optimum population.

The expectation of life is highest in New Zealand with 63 years for a male child and 65 years for a female child at the beginning of this decade. In Germany, in 1925 the average expectation of life was 56 years for boys and 58·8 years for girls. The expectation of life now is 59·10 years in the United States. In India the expectation of life is lowest with 22 and 23 years for a male and a female child respectively, or about that prevailing in Roman Empire. According to Irving Fisher in the first quarter of the 20th century for the United States, England and Germany, life lengthened at the amazing space of 40 years per century. The health-workers in Europe and America are confident that many

nations may allow such knowledge of the laws of health appropriate to each age and occupation, to each climate and race, that within the next fifty years as much as twenty years may be added to the expectancy of life which now prevails.[11] Dublin points out, however, that recent gains have been confined to the early years of life. For those who have reached the age of 40 there has been hardly any progress since 1880. The duration of life is adaptive. As Weismann observed long ago, the length of an animal's life has been punctuated from without in relation to the particular conditions of its struggle for existence.[12] The preservation and increase of the organically superior classes in society and hence a high average physical and mental fitness as well as a high average expectation of life are the criteria of racial soundness and race progress. It is not for the welfare of the species that the urban populations having drawn from the villages an undue proportion of the best elements of the nation show a decline of fecundity, or that a disproportionate proportion of the population is born in homes poor in natural qualities as well as in "traditions". Industrialism and the consequent disparity of wealth and opportunities have not always favoured the multiplication of the alert and vigorous middle class, richly endowed in qualities essential for leadership and social co-operation. On account of differential fecundity a degenerate type of physical characters and inheritance is more prominent now than a few generations back. Large mortality in early life and short span of vigorous middle age are equally detrimental to the race. It is not improbable that if both selective fecundity and selective mortality continue to change unfavourably the character and inheritance of the race, industrial civilisation will be jeopardised. Man has successfully combatted child mortality but so far his fight against old age has not been entirely successful. On the other hand, the growing pressure and delicacy and complexity of the social organisation have often brought about old age prematurely. Man has not cultivated the rest

(11) See Ross: *Standing Room only?* p. 77.
(12) See Thomson: Everyday Biology, Ch. XX.

habit, and this has cost him dearly. On the whole premature senility and the shortening of the span of life exhibit man's imperfect adjustment to the civilised environment.

The discovery of Steinach and others and the renewal of human vigour by gland-grafting, however, open out possibilities of human rejuvenation or at least the extension of active middle age. But the moot question remains, if the brain refuses to accept new ideas or be charged with new emotions and aspirations, the change of internal secretions will not add much to the joy of life, labour and leisure.

NEED OF ECONOMICAL AND SELECTIVE REPRODUCTION.—The pressure of natural selection upon man is relieved in great measure by his control over the environment, the security of food-supply, the relaxation of hard manual labour and the conquest of disease. But man by his prolification under the favourable conditions afforded by his mastery over nature often upsets the balance of the region with which a numerical stability of all living communities, including human, co-exists. Thus man's a-symbiotic multiplication is bound to produce the same effects as are produced amongst organisms in the lower scale of evolution which experience both 'storms of breeding and death'. This phase of severe natural selection that is the normal sequel of a 'breeding storm' is, however, often avoided in the human community both by the lowering of vitality and consequent increase of mortality and decline of birth rate. But the most desirable method of selection is the new found economy of reproduction,—birth control and selective breeding. The selection which is left to Nature is by killing and devitalisation, which are both relentless and haphazard and these should be replaced by man's deliberately controlled and preferential reproduction, which allows the best types to evolve under most favourable conditions. A human population which breeds like field-rats and rabbits without prevision and without selection pays scant respect to man's social heritage and his dignity. Man must cultivate a more tender regard for the woman as the mother of the race and for the child as

the promise of the future, and learn to be more economical in his methods of reproduction in order that he might have more capacity and leisure for social and cultural progress. The tenure of an animal's life has been determined by natural selection in reference to big issues—notably the rate of reproduction and the average mortality. As civilisation progresses, man will control both natality and mortality more and more effectively. But this does not imply that selection will cease and biological progress will be brought to a close. Man will direct his attention to improve the quality of his species by preferential breeding of the best types. A high average expectation of life and a moderate and selective reproduction are the criteria of a progressive type of human population even though man gets his release from those destructive tests which maintain a numerical balance in other animals.

CHAPTER XI.

TRENDS AND CONSEQUENCES OF OVER-POPULATION.

Climate, Population, and Food Supply.—A warm and humid climate by leading to early maturity and reducing food requirements encourages the growth of a dense population. At the same time it depresses muscular and nervous functioning, health and vigour. Thus high density, low plane of living, and low expectation of life co-exist. On the other hand, both soil fertility and abundant rainfall in summer ensure an easy food-supply for the multiplying numbers, though the technique and mode of agriculture remain the same for generations. In the Ganges valley man can live on little, while his weight and stamina are less than in cold climes. His metabolism is lower. Therefore his system requires a lower nitrogenous balance and his dietary need not be rich in proteins and fats. For the rest, it is simply a case of mathematics, as among insects and animals. So much land is available for cultivation; with irrigation and intensive farming so much crop can be raised per acre, and so much is necessary for each family. The population expands until the limits of intensive farming and irrigation are reached. It lives at the bare subsistence level; and no surplus crops being raised, the rate of reproduction expands or contracts in sympathy with the increased or diminished food-supply (or the conditions of rainfall generally). The rate of mortality also contracts or expands in sympathy with good or bad harvests. This will be evident from the movement of birth and death rates during 1901-1921 in several districts of the Indo-Gangetic plain, which show a heavy population pressure. The closeness of the correspondence shows that the masses do not obtain a chance of child-bearing by separation from home in search of employment, etc., when harvests are unsatisfactory, while actual under-nutrition greatly diminishes vitality and fecundity and lowers the birth-rate.

The relation between sterility and malnutrition has been traced in many countries. In feeding animals on diets extremely deficient in Vitamin B, McCarrison noticed in 1918 that atrophy of the testes was one of the earliest effects. During famines, sterility in women abortion and failure of the menstrual functions have been recorded as evidences of malnutrition.[23] No doubt the consumption of wheat, which contains Vitamin B, is considerably reduced, if it does not altogether cease, during a year of scarcity or famine; while milk and milk products, as well as some fresh vegetables—all rich in Vitamin E, which also is considered favourable to reproduction—are entirely eliminated from the diet. On the other hand, scarcity or malnutrition increases the death-rate. The close correspondence between mortality and bad harvests indicates that the diminution of birth-rate is due mostly to the lowering of vitality, the whole population being at the subsistence level. Starvation is the ultimate check on human numbers, but before this check operates on a large scale, which would be disastrous to the human community, since the mortality would not be selective, there is a lowering of both natality and vitality which reduce numbers when these pass beyond control of the normal checks. Both vitality and mean duration of life in India are low. The average expectation of life is 26·5 years as compared with the average of 50 years in most European countries. It appears that the density in some of the "super-saturated" districts, which is already much higher than the optimum density, remains stable, or is actually decreasing; but, obviously, the stabilized density must be greatly lowered, *i.e.*, there must be lower death-rate and corresponding lower birth-rate, before India can approximate to the average expectation of life in the West.

MATHEMATICAL FORMULA FOR POPULATION PROBLEMS.—We may express the notion of optimum population in a single formula as follows:—

$P_p \times \text{Prod} = \text{S.}\, P_T$ (1).

Prod=F (Soil index, Index of Aridity, Irrigation).

(23) *Royal Commission on Agriculture in India*, Vol. I, Part II, Evidence.

Optimum population cannot be defined excepting as the co-factor of some "optimum" standard of living. But it is difficult to see how any such standard of living can be defined unless perhaps by means of the idea that there exists a definite standard of living, say S, such that if S is greater than S_1, in any society, that society possesses luxuries which in the long run are physiologically detrimental; while if S is less than S_1, there is starvation in a greater or less degree, leading to increased predisposition to disease and mortality. Thus a high standard of living implies, physiologically speaking, a high average expectation of life, which ensures the optimum productivity of the individual. Now the average expectation of life is the outcome of a complex process of adaptation of individual characteristics to the needs of the environment. Pearl observes: "Perhaps the best single measure of the constitutional soundness—strength or weakness—of the individual is his duration of life. This datum is a single numerical measure of the combined effect on the organism of all factors, hereditary and environmental, in the broadest sense of these words, which influence its life-history."[24] The duration of life is undoubtedly inherited, and represents a most satisfactory index of the constitutional superiority or inferiority of the people. If this be correct, S_1 is the optimum standard of living, as measured by the expectation of life, and the value of P given by (1) is the optimum population.

Productivity is the number of calories produced by each producer and S is the number of calories consumed by each consumer.

The formula (1) assumes that the consuming population absorbs all calories produced. If there is export, for instance, (1) must be replaced by $P_P \times \text{Prod.} = (S \times P_T) + E$, where E is the number of calories exported. If calories are imported E would be negative. But if export takes place the condition is not an optimum. For we could increase either S or P_T or both by utilising the surplus E.

(24) *Studies in Human Biology*, Chap. XII, p. 355.

In the case of import, a stoppage of the import would diminish either S or P_T or both.

But either export or import assumes that the adjustment of the population to the food-supply is not the closest possible. If the adjustment is the closest possible E = O, and (1) holds good.

The optimum population, then, is merely

$$\text{Optimum } P_T = \frac{P_p \times \text{Prod.}}{S_1}$$

where S is the optimum standard of living, as judged by the highest mean duration of life.

When we have determined the optimum population the maladjustment in any particular society may be measured.

If we express it as a percentage of the optimum population it will be where P_O is the optimum population, and A is the actual population.

$$P_o - A$$

In a case like the central or eastern portion of the Ganges valley, where the food supply is barely sufficient to support existence, we cannot say that S_1 is ever attained. The condition $S < S_1$ is permanently satisfied. A slight increase in the food-supply is immediately followed by an increase in population which tends to reduce S to that value which represents bare existence. On the other hand, a slight diminution of the food-supply, as the result mainly of deficient or irregularly distributed rainfall, tends to be followed immediately by a higher rate of mortality and decrease in population. The success or failure of the harvests influences the prevalence of epidemics, the mortality, and the rate of reproduction, and thus brings about the adjustment between population and food-supply. This will be evident from a closer study of the relation between fluctuations of the total area cultivated and the rates of reproduction and mortality in typical districts of the Ganges valley.

Increase in productivity alone will never produce optimum conditions. Nor will increase in the producing population alone, nor both together if P_T also increases. In order to attain any value of S above the minimum necessary for subsistence we *must* limit the total population, if P remains fixed. In other words we must increase the value of the ratio P_T or the value of the productivity or both.

In the Gangetic plain the ratio is for all practical purposes a constant. The number S is more or less permanently fixed at its minimum subsistence value. Productivity depends much less on the soil index than on rainfall and irrigation, excepting in the newly formed deltaic area, the reason being that the whole of the valley is now in a mature stage.

Productivity, therefore, depends on the soil index, the index of aridity and the percentage of irrigation.

It appears, then, that the population of large parts of the Ganges valley, after reaching a certain density, shows a tendency towards diminution. The primary cause which stabilises the population is a higher death-rate rather than a falling birth-rate; since, as early as the next favourable agricultural season, the birth-rate leaps up and the vacuum created by increase in the death-rate disappears. It is the enormous increase in the death-rate which primarily controls population density. It is obvious that human numbers tend to approach the equilibrium density, and also that the optimum density is much smaller than the equilibrium density.

OPTIMUM DENSITY AND EXPECTATION OF LIFE.—The distinction between optimum density and equilibrium density is of value only to a community where psychological factors play a dominant part in the control of numbers. We have already seen that the terminal animals control their numbers by a lower rate of reproduction. The territorial division, both among birds and carnivores, represents an indirect operation of both psychological and economic factors in controlling their numbers. Among the small gregarious herbivores, however, density rapidly

increases and, after it has already increased a good deal, fecundity, far from being reduced, is actually increased. Thus rabbits, lemmings, field mice, etc., Julian Huxley observes, have cycles in which the population increases gradually to a maximum, and then, through an epidemic, is brought down rapidly to a minimum. The same holds good of masses of congested mankind in India and in China, among whom the equilibrium density is reached as in the case of rabbits and field mice by an enormous and even catastrophic increase in the death-rate, showing itself in epidemic diseases, when the population reaches a certain level. When we speak of an optimum for human numbers, on the other hand, we should seek as our standard the maintenance of conditions of maximum physiological well-being S_1, and not the minimum subsistence value at which S seems to have been permanently fixed in India or China. Therefore optimum density of population is that where we have the *highest average expectation of life.* We have already seen that longevity and the mean age are greater among the higher social classes than among the lower in all countries. The average expectation of life is diminished by poverty as well as by luxury, and we can take a high average expectation of life as an excellent index of economic, social and moral progress.

MIGRATION NO SOLUTION.—In the congested plains of India and China there is no attempt to reach a higher grade of physiological or social well-being. Both the average expectation of life and the standard of living are exceedingly low, and are further lowered when a favourable agricultural season creates more mouths to feed. Population here tends to reach not an optimum but an equilibrium density as the result of a gradual or sudden increase in the death-rate, or sometimes even a decrease in the birth-rate. Mal-nutrition, through the deprivation of calcium and vitamins contributes to diminish fecundity; the increase of infantile and maternal mortality, due to the indirect effects of mal-nutrition alters the age and sex composition of the community, resulting in the long run reduction of the rate of population growth. That the

birth-rate shows a marked diminution in the more crowded of the major provinces is shown below:

	Birth-rate per 1000	
	1901—1910	1929—33
U. P ..	41·4	36
Bihar ..	41·0	34
Bengal ..	35·5	27

Migration is too small to affect the problem of population adjustment, as the following figures from the United Provinces would indicate:—

POPULATION AS AFFECTED BY MIGRATION.

	Percentage of provincial area.	Percentage of provincial population.	Population	Density (rural portions only).	Migration.	Percentage of migration to population.
Indo-Gangetic Plain, West ..	22·50	26·90	12,146,000	433	144,000	1·2
„ Central ..	21·20	26·30	11,920,000	477	242,000	2·0
„ East ..	7·00	11·50	5,248,000	648	376,000	7·0
Sub-Himalaya, West ..	12·00	17·00	7,730,000	584	58,000	0·7

Here we have a human situation that illustrates the same formula of the trend of numbers in relation to area and food-supply as fruit flies breeding in a jar or rodent populations confined to a particular territory.

NATURAL CHECKS TO DENSITY—THE "VITAL INDEX.—Comparing the trend of population density, and birth and death-rates for over three or four decades in some districts of the Ganges plain, Upper and Central, we find that mortality tends to be greater than natality after a certain equilibrium density is exceeded, and, in a few cases, we even find that the birth-rate is permanently affected. Such changes affect both the quality and quantity of the population and tend to keep numbers well below the density at which starvation faces the population. Starvation influences in various indirect ways, by lowering the resistance to attack by parasites, or to the weather, and also by reducing the capacity for toil. But it appears that starvation seldom acts as a direct check on numbers, although the possibility of it is always present. As Elton observes in the case of animals: "The maximum numbers feasible for an animal at any moment are not only determined by the food-supply at the moment, but must be

adjusted to the needs of the future. It would be an unworkable system for animals to live all the time up to the extreme limits of their food-supply, since no margin would be left for the times of scarcity which are always liable to occur." We have already noted how the general system of food-cycles and food-chains tends to keep each species of animals to a certain optimum density, neither too low nor too high, which is not the same at different times, or in different regions. In human population the equilibrium density seems to be maintained by decrease in the survival-rate, which keeps down the numbers below the point at which starvation operates directly in the limitation of numbers. Nature, we find, has a safety-valve in the forces of natality and mortality, which do not permit animal and human populations to multiply up to the extreme limits of food-supply for no system of living community can work unless there is some adjustment to the needs of the future. With animals as well as humans migration in response to an unfavourable habitat acts as a sort of safety-valve reducing the chances of starvation and resulting in a readjustment of the density of numbers in different places. Elton, indeed, emphasises the importance of the migratory tendency of animals as contributing towards a solution of the animal population problem and offering a means of enormously increasing the possibilities of adaptive radiation.[25] The study of human numbers in the congested Ganges plain, where migration may be roughly estimated as amounting to only 5 per cent. of the total population seems to support the older hypothesis that adaptation is produced by the elimination of the unfit from a stationary population of animals in which new hereditary variations are constantly being produced. Both natality and mortality are here matters of ecologic adjustment striking out a normal balance of numbers with the ecological area, where the evolutionary processes are at work with whole and more or less sedentary populations. Accordingly the movement of population in certain areas of the Ganges valley is similar to that of bacterial popu-

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(25) Elton: *Animal Ecology and Evolution.*

lation confined in a test tube, or of rodent population in a certain range of territory, tending to follow Pearl's logistic curve. In what decade the equilibrium density has been reached in a particular district depends upon agricultural and, especially, hydrographic conditions. But no sooner is it reached than we find the tendency towards a decrease of density either through a decreasing survival-rate or through a permanent lowering of the birth-rate. Statistical evidence of this tendency will be furnished by some of the congested districts of the Ganges Valley where the population after reaching saturation density, tends to show a lower biological vigour as indicated by the "vital index". (100 births÷deaths.) This constant has been effectively used by Pearl to measure the biological health of a population and to indicate its probable future course. If the ratio 100 births÷deaths is greater than 100 the population is in a growing and in so far a healthy condition. If it is less than 100 the population is biologically unhealthy. No single formula gives so sensitive a measure of the vitality of a population. Sweeney describes the vital index as the measure of the evolutionary survival value of a population. From the vital indices we may easily conclude that the populations, after having overstepped the equilibrium density, have become biologically unhealthy.

The following tables show the movements of density and the vital indices of certain districts of the United Provinces where the symptoms of over-population are evident:—

MEAN DENSITY.

	1872	1881	1891	1901	1911	1921	1931
Agra ..	580	525	541	572*	551	498	567
Aligarh ..	551	525	536	617*	599	546	602
Cawnpore ..	483	498	510	531*	482	485	511
Etawah ..	395	427	430	477*	449	434	442
Lucknow ..	805	721	801	820*	790	749	813
Muttra ..	540	463	492	526*	452	427	461
Allahabad ..	490	516	542*	521	610	491	524
Jaunpur ..	662	780	816*	776	746	745	797
Ballia ..	584	784	800*	794	680	680	752
Benares ..	788	885	914*	875	890	899	931
Meerut ..	544	560	593	657	641	653	702

*Equilibrium density.

VITAL INDICES OF DISTRICTS IN THE UNITED PROVINCES AT QUINQUENNIAL PERIODS.

Districts.	Years of equilibrium density.	Vital indices before the year of equilibrium density.				Vital indices after the year of equilibrium density.								Vital indices in the year of epidemic outbreaks.		
		1881	1886	1891	1896	1901	1906	1911	1916	1921	1923	1930	1933	1905	1908	1918
Agra ..	1901	145·5	100	165	133	142	94	98	161	108	143	162	174	52	54	79
Aligarh ..	1901	180	96	143	150	153	121	90	185	105	138	155	180	92	52	31
Cawnpore ..	1901	106	109	92	121	126	63	94	155	84	130	123	159	86	86	42
Etawah ..	1901	126	92	110	155	150	75	93	161	88	132	146	186	118	62	43
Lucknow ..	1901	125	121	99	113	113	103	93	89.6	97	152	92	121	75	59	44
Muttra ..	1901	138	90	136	147	118	98	98	189	116	123	112	181	36	39	28

We have taken quinquennial periods from 1881 to 1921. The vital indices of 1916 show the effects of abnormally good harvests. The damage done by the epidemics to these populations is much severer than elsewhere.

EVIDENCE OF AGE-GROUPS.—That the major portion of the mature valley, where high density and high percentage of cultivated to cultivable area co-exist, is now in a stationary biological condition, may be shown by another method.

The Swedish statistician, Sündbarg, divides the population of a country into the following age-groups, 0-14, 15-49, and 50-onward (pre-maturity, maturity, and post-maturity), and distinguishes between progressive, stationary, and retrogressive types according to the percentages of population in the pre-maturity and post-maturity phases; 50 per cent. of the population in all countries, where the figures are not upset by migration, falling in the maturity period.

SÜNDBARG'S TABLES.

PER CENT. OF POPULATION.

AGE GROUP. Years.	Progressive Type.	Stationary Type.	Retrogressive Type.
0-14	40	40	20
15-49	50	50	30
50-onwards	10	17	30

In India the mature period for women begins earlier and is shorter and old age comes quicker than in Sündbarg's formula, while a large number of women in the child-bearing period are widows and cannot be remarried.

Gait, in his *Census Report of India,* took 15-40 instead of 15-50 age period as his basis of Indian comparison. On this basis the table for the different areas of the Ganges plain will be as follows:—

GAIT'S MODIFICATION FOR INDIA OF SÜNDBARG'S TABLES.

	Age Period.			Density.
	0·15	15-40	40-onward.	
Indo-Gangetic Plain, West—	37	41	22	508
Do. Central ..	35	41	24	527
Do. East ..	39	38	23	711
South Bihar ..	37	55	23	642
North Bihar ..	37	40	23	502

Thus population in the areas in Bihar and the Indo-Gangetic Plain, Central, represents a more stationary type than in the other areas. All the areas are in facts less progressive than what could be deduced from the former table. For, while Gait was right in assuming that old age comes on in India at 40 rather than 50, he might have taken 0-12 as the age-group of children, because puberty also appears earlier in India. In the Indian population the proportion of children in the age-group 0-12 should be compared with that in the group, 40 and over, and the numbers will approach greater equality as Sündbarg and Gait's bases of comparison are modified. Further, the larger number of unmarried males and widowed women in the effective age in India has also to be considered:

CIVIL CONDITION AT 15-40 PER 1000 OF EACH SEX.

	Males		Widowed		Females.	
	Unmarried.	Married.	Unmarried.	Married.	Unmarried.	Married.
Indo-Gangetic						
Plain, West ..	271	644	85	32	864	104
Do. Central ..	240	682	78	34	860	106
Do. East ..	205	205	84	24	852	121

Early marriage is more prevalent in the Central and Eastern plains than in the West, while the number of widows also is greater in the former, especially in the East.

Using Gait's modification of Sündbarg's table, we obtain the following district data for females, which will enable us to compare the number of females under sixteen with those who are now in the effective ages. This is another method of ascertaining whether the population will reproduce itself or die out.

FEMALES AT AGE PERIODS, PERCENTAGES.

	0-15	15-40	40-onward
Indo-Gangetic Plain, West:			
1. Meerut ..	37·9	39·6	22·5
2. Aligarh ..	36·9	40·5	22·6
3. Muttra ..	38·2	38·5	23·3
4. Agra ..	37·5	40·7	21·8
5. Etawah ..	37·5	41·7	20·8
Indo-Gangetic Plain, Central:			
6. Cawnpore ..	35·9	41·3	22·8
7. Allahabad ..	37·3	39·9	22·8
8. Lucknow ..	34·3	39·9	25·8
Indo-Gangetic Plain, East:			
9. Benares ..	38·4	37·9	23·7
10. Jaunpur ..	37·9	38·8	23·3

All the above districts are found by this test to be decaying. Agra, Etawah, Aligarh, Cawnpore, and Lucknow seem to be especially deficient. When the group 0-15 females reaches child-bearing age, it will not completely replace those who are now in the ages of 15-40; *i.e.*, the population is not maintaining its numbers.

In East Bengal, on the other hand, in the active delta, the progressive type of population is well in evidence; while in the moribund delta the population tends to be more consistently retrogressive than anywhere else in the Ganges valley.

FEMALES AT AGE PERIODS, PERCENTAGES.

		0-15	15-40	40-onward
East Bengal' Actlue Delta:				
Noakhali	..	44·9	40·9	14·2
Bakarganj	..	41·7	42·1	16·2
Tippera	..	44·0	42·1	13·9
East Bengal, Moribund Delta:				
Jessore	..	35·6	43·7	20·7
Nadia	..	35·7	42·6	21·7
Murshidabad	..	36·9	42·4	20·7

The moribund delta maintained a teeming population in the medieval period; but to-day the inevitable coming of age of the alluvial plain, coupled with man's inexpert interference with the natural drainage channels owing to increase of population, has brought about stagnation and decline.

AGRICULTURAL CONGESTION AND ITS RELIEF.—Overcrowding in the Ganges valley is mostly the outcome of excessive pressure of population on the land. We may illustrate this from the distribution of occupations in Gorakhpur district in the United Provinces. Such occupational congestion may be relieved by reducing the pressure of numbers dependent on agriculture, and increasing the number of workers in the occupations which are at present understocked.

OCCUPATIONAL DISTRIBUTION PER 1.000 OF POPULATION IN GORAKHPUR DISTRICT.

			Percentage of	
			Workers.	Dependents.
Agriculture	..	918	62	38
Industry		32	59	41
Commerce		20	57	43
Professions		21	38	62
Others		9	59	41

The pressure of population on the land is now mitigated in the Gorakhpur district by (*a*) the utilisation of waste and fallow areas, (*b*) extension of double-cropping, (*c*) the introduction of improved and heavy-yielding crop varieties. and (*d*) extension of well-irrigation as a provision against years of deficient or irregular rainfall.

The symptoms of over-population may now be closely surveyed and summarised:—

The existing distribution of population in the Ganges valley is in very close agreement with the conditions of rainfall and irrigation, *i.e.*. agricultural water-supply; so close that it may be asserted as a general proposition that the populations in the different geographical areas of the vast plain have so nearly reached the limit of their resources as to render aridity and irrigation the limiting factors in governing growth and density of population.

Density of population depends primarily on the proportion of land which is cropped more than once, *i.e.*, on intensive farming, the percentage of net cultivated area having reached a high figure.

Density of population increases at a greater rate, district by district, than the proportion of land which is cultivated or is cropped more than once.

The increase of density of population outstrips the increase of total net-cropped area.

Since it may be assumed that at any given time the population which can exist on any given extent of land consistently with the attainment of the maximum return of agriculture possible at the time is definite, an increase in density of population leads to a disproportionately small increase in returns.

Though the existence of over-population must elude exact demonstration it may be inferred from various social and economic phenomena.

The greater the increase of density, the smaller the size of holdings, and consequently the greater the family labour which remains idle or under-employed.

An increase of irrigation facilities stays the pressure population on the soil.

Similarly the introduction of valuable and heavy-yielding crop varieties constantly shifts the point at which the agricultural returns cease to increase and begin to diminish.

In the heavily populated areas of the Ganges valley irrigation has almost reached its limit and no longer determines population density. Agricultural modes and practices have also reached more or less a static adjustment to conditions of soil and water-supply.

Thus an increase of population leads more often to a reduced standard of living than to increased agricultural productivity.

A lowering of the standard of living and agricultural under-employment go together.

Throughout the heavily populated areas the size of the peasants' holdings has become uneconomic. The increase of population density has led to fractionalisation, so that the majority of the cultivator's holdings are below three acres, an area insufficient to maintain him in security and comfort without any supplementary income. The small-holder usually supplements his earnings by working on the fields of other cultivators. There is a mass of floating agricultural labour working on exceedingly low wages.

The holdings have sometimes become so small that the cultivator has to discard the cattle and use the spade. In some areas women may be seen drawing the plough, as in China.

Nowhere else do the vicissitudes of agriculture influence so comprehensive a series of social phenomena, affecting the whole fabric of man's life. An increase or decrease of food-supply increases or reduces the rate of reproduction and has opposite effects on mortality. The relationship between public health and agriculture is intimate. Birth-rate and mortality, or prevalence of disease, very with the condition, of the harvests. Crop conditions measure the health, vitality and efficiency of the

people. While the curve of natality is closely parallel to the curve of cropped area, the mortality curve moves in an exactly inverse order.

From these data it will appear that there is over-population in the following implications:

(1) There is no possibility of an improvement in the standard of living, since intensive farming and irrigation facilities have nearly reached their limits.

(2) Over long periods the cumulative effect of mortality rates exceeds that of natality, so that in the long run the trend of population is in the negative direction.

(3) Population cannot maintain itself in its present density as shown by the loss of resistance of the general population, making it vulnerable to epidemics, and especially the infants, women of the reproductive age and older individuals. Through a reduction of quality or vitality of the population, the net reproduction rate is reduced. There is also a gradual slackening of birth-rate. Such reduction is brought about through the selective effects of mal-nutrition and of mortality which alter the age and sex composition.

The following conclusions relating to the quantity and quality of the population may be deduced:—

(1) Having overstepped the equilibrium density, population is now brought back to it through a steady increase of mortality, and sometimes a reduction of birth-rate. The check to population is generally of the rodent population type, as shown in an increase of mortality, and especially in the form of epidemics such as plague, influenza or malaria. The fruit fly type of check, *viz.*, reduction of birth-rate with density, also operates. The greater the approximation of numbers to an equilibrium density through the lowering of the survival-rate, the more remote will be the indiscriminate reduction of the population by actual starvation.

(2) High infantile mortality reduces the birth-rate through the diminution of the proportion of adults in the total population.

(3) High mortality among persons of the child-bearing age, and especially maternal mortality, reduces the birth-rate.

(4) Epidemics, which may affect persons of the child-bearing age reduce the birth-rate.

(5) An increase of the disproportion of sexes, (*i.e.*, paucity of females) also indirectly reduces the birth-rate.

(6) The adjustment of human numbers to food-supply is so close that slight variations in the cropped area are accompanied by marked disturbances in the trend of reproductivity and mortality. The standard of living is the lowest consistent with the bare maintenance of life, as would appear from the fact that there is no margin of reserve to permit of birth and death rates being maintained anywhere near the normal, when there is a slight variation of food-supply as measured by the cropped area. On account of the great instability of agriculture in this environment, and the population not exercising its normal checks over long periods, food-supply and economic toil have direct relations with natality and mortality, and through these restore the equilibrium between density and the region. Birth and death-rates are thus matters of ecologic adjustment, and starvation hardly operates directly as a check. Men have lost or broken out of control of the various checks which among animals keep down numbers to reasonable proportions, while leaving a margin for times of food-scarcity which are normal; but nature re-establishes a a suitable density by bringing into operation the ecological mechanisms of a lower birth-rate and vitality rather than the direct check of starvation, which does not act selectively, but effects a wholesale and indiscriminate reduction of numbers. With the decrease of survival-rate the population gradually becomes restored to a more stable density, though the optimum density of the region as judged from the highest expectation of life is far from being reached. Meanwhile industrial employment and migration might also serve to counteract the lack of balance between human numbers and the resources of the region.

(7) Crime against property increases when harvests are bad and diminishes when they are good. Starvation not only leads to crime directly by snapping domestic and social ties, but also indirectly by leading to unemployment and wholesale emigration to distant places where the usual community means of social control do not operate.

The volume of emigration also corresponds to the condition of the harvests.

The process as a result of which the natural checks of numbers have ceased to operate is complex, and connected with the whole texture of social life; but the factors may be analysed somewhat as follows:—

(1) In the Ganges plain, climate has contributed to earlier maturity, the majority of females being capable of matrimonial life by the age of 15, however unfit for it they may be physically. Thus the reproductive period is prolonged.

(2) In the Eastern portions of the plain the race is more mixed than in the Western portions. Where the lower castes and lower branches of widespread castes dominate, the rule of child-marriage is adopted more strictly. Accordingly the age of puberty is somewhat earlier and infant marriage more common in the Eastern than in the Western districts of the valley.

(3) The custom of universal marriage, without regard to economic considerations, has received the sanction of religion, while the desire to bear and beget children has been transmuted into an ethical obligation.

(4) A high development of parental impulse has also contributed to encourage multiplication.

(5) The low social position of the woman, who is also protected in some degree against hard work in the fields by taboos, also encourages frequent child-bearing, without regard to her physical suffering or economic incapacity.

(6) Precariousness of agriculture, due to the irregular distribution of rainfall, has in some measure diminished thrift and prudence.

(7) A faulty land-distribution has discouraged the accumulation and investment of capital by the small-holder. The change from cultivating proprietorship to tenantry, and from tenantry to the proletariat, has sapped initiative and desire for a high standard of living.

The general effect is that the checks which normally govern numbers in human society have been in some degree nullified, and as a result both the quality and quantity of population are being reduced in a manner unparallelled elsewhere. The population is on a downward grade of standard of living and physiological status.

To illustrate many of these phenomena it would be more convenient to study areas smaller than a district.

INCREASE OF DENSITY.

	1872	1881	1891	1901	1911	1921	1931
Gorakpur District ..	443	574	657	649	707	721·5	787

INCREASES OF DENSITY AND CULTIVATION.

	Normal Rainfall.	Percentage of net-cropped to.	double-cropped to cultivable area.	irrigated to gross cultivated area.	increase of population density 1872—1921.	increase of total net-cropped area-cultivated area 1891—1924.
Gorakhpur District ..	48·15	82·7	22·7	28·0	63·2	4·4

EXCESSIVE SUB-DIVISION OF HOLDINGS.

Subdivisions in Gorakpur Dist.	Density.	Average size of tenants' holdings in acres (Subsistence holding, 3 acres).	Tenants whose holdings are too small to maintain cattle, which consequently are borrowed or hired.
Deoria (Salimpur Majhauli).	1,100	.65	11,744
Sadr ..	1,044	2·1	10,034
Bansgaon ..	1,014	1·4	9,872
Hata ..	992	·9	9,580
Padrauna (Sidhua Jobna).	865	1.3	10,454
Maharajganj ..	716	2·5	6,828

CROP IMPROVEMENT AND EXTENSION.

	Years compared.	Wheat Mixed.	Peas and Masur.	Sugarcane.	Early Rice.	Maize.	Oil-seeds.	Gram.	Late Rice.	Linseed.
Sadr										
Maharajganj	1889	104,884	82,517	9,554	313,651	15,951	117,680	108,803	111,267	..
Bansgaon	1922	159,203	108,799	22,414	458,878	17,823	48,255	61,637	101,263	..
Percentage of increase or decrease.		+34·11	+24·15	+134·8	+46·3	+11·7	58·9	43·3	8·9	..
Deoria										
Hata	1889	252,865	133,357	85,376	182,405	51,003	..	..	..	57,713
Padrauna	1922	254,923	202,827	10,009	261,179	77,627	..	..	..	33,421
Percentage of increase or decrease.		+·8	+51·2	+17·2	+43.1	+52·2	..	..	..	72·6

CONSERVATIVE AGRICULTURE IN CHINA.—It is well-known that rotations of leguminous and grass crops restore a great deal to the soil through the cover of vegetation and nodules or decayed steams laden with bacteria. King wrote of the Chinese farmers: "Centuries of practice had taught the farmers of the Far East that the culture and use of the leguminous crops are essential to ensuring fertility, and so the growing of legumes in rotation with other crops very extensively for the express purpose of fertilising the soil is an old, fixed practice." In China a striking example of crop introduction has been seen in the case of pea-nut and soy-bean. It is considered that a soy-bean contains all the elements necessary for normal growth and that its protein appears to be quite as valuable as the casein of milk. It is the only known seed meeting these requirements. The market price of an equivalent of one hundred calories of beef is thirty times as great as for one hundred calories of the beans.[1]

VEGETABLE PROTEIN.—A high density of population has led both in India and China to the emphasis of vegetable protein, leading more or less to the exclusion of beef. Apart from the use of leguminous crops in India and China in restoring soil fertility, these serve the all-important purpose of balancing the preponderance of starch diet by the supply of vegetable proteins. Food production has thus been adjusted as closely as possible to the requirements of a dense population; but, if there is no end to the number of mouths to fill excepting as they are kept in check by under-nutrition and disease, the population is in the same plight, to use East's phrase, as were the daughters of Danaus, for ever carrying water in a sieve.

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(1) See Mallory: *China, Land of Famine*, p. 113.

CHAPTER XII.

ECONOMY OF FOOD AND SOIL.

CALCULATION OF MAN'S FOOD REQUIREMENTS.—The study of optimum population at the existing stage of agriculture of a country ultimately touches on the economic problem of alternative uses of land and the food peculiarities and standards of living of various regions. The scientific method of estimating population capacity is to treat agricultural yields, including meat and dairy produce, in terms of calories. Professor Pearl has made on this basis a statistical study of America's food requirements,[1] and Taylor has made a survey of the calory needs of a population of 175,000,000 which, following Pearl, he assumes the United States will have by 1980.[2] On similar lines India's population capacity has been estimated at 447 millions which at the present rate of increase will be overstepped before the end of a quarter of a century. India's present food supply yields 280·4 billion calories which her present food shortage is 41·1 billion calories[3]. We have already seen that climate must affect the quantity of calories needed. Maurel, a French physician, estimates that the number of calories necessary for a male adult weighing 55 kilograms and performing light work varies theoretically from 1,650 in hot seasons in hot climes to 2,750 in cold seasons in cold climes. Hard work has done in India and Japan on the basis of 2,000 calories as compared with 5,000, which was the British war ration, and 3,300, which is estimated to be the average requirement of a Briton engaged in sedentary pursuits. Burridge finds from a recent survey of the peasant's diet in the United Provinces that it gave its caloric energy as 2,400 and, allowing for 10 per cent. waste, as 2,160 as against 3,500 for a British workman of 67 kilograms' weight working 8 to 9 hours per day; but

(1) *Studies in Human Biology*, Chapter XIV and XV

(2) *See* "Population Problem since the World War" *Journal of Political Economy*, October, 1928.

(3) *Mukerjee*: Population, Capacity and Control in India, Convener's Address before the first Indian Population Conference, 1936.

the latter diet would not be suitable for work in the Indian sun as is that of the Indian coolie, who is very much in the dietetic position that the non-fighting German population were during the war. He observes: "It is evident then that whenever it is easily possible for heat production to outstrip heat loss, work can be more safely and economically done at the expense of fats and carbo-hydrates, and the low nitrogen value of Indian diets has probably been determined through this factor. It may be that the virile race develops in a particular country because its climate makes a high nitrogenous exchange possible. The Indian ryot, according to European standards, has a low level of nutrition which may cause fatalism but may fit him better for his actual task."[4] A further and detailed investigation at the physiological laboratory, Lucknow University, of the basal metabolism of a peasant of the United Provinces showed that the number of calories needed was 1,200 as compared with the resting need of 1600—1800 calories in the U.S.A. For a professional man doing sedentary work the requirement is 1000 calories.[5] There are reasons, then, for believing that the amount of energy expenditure per diem in work is less in warm than in cold regions.

DIETETIC COMPARISONS.—Much depends also on the general standard of physical measurement. The food requirement of an average American is based, for instance, on the average body weight of 70 kilograms (154 pounds). In India we have to base our calculations on an average weight of 50 to 60 kilograms of a different stock. The weight of an Indian has been found among different tribes and communities to be 10 to 20 per cent. less than the standard weight of a European. Professor Morimoto estimates that a Japanese may be fairly expected to consume only 80 per cent. of what a foreigner needs, for the average weight of Japanese is only 52 kilograms to the American's 64 kilograms. As a matter of fact, Japanese consume much less food than Americans.

(4) *Royal Commission on Agriculture*, Vol I, Part I, Evidence, page 157.

(5) *Niant Dhan Banerjee* conducted certain experiments in King George Medical College Laboratory.

It has been estimated that the amount of food consumed by the Japanese is only 66·5 per cent. of that consumed by the Americans; but, on the basis of the bodily weights of the two peoples, the ratio ought to be about 81 per cent., while the ratio should be 87 per cent. if the comparison is based on the area of body surface. Dr. Ingaki has made allowances of 25 per cent. and 7·5 per cent. for the food wasted by Americans and Japanese respectively, and computed the food calories consumed by the two peoples, giving as result the Japanese as consuming 82 per cent. of the amount consumed by Americans—both by weight and calorie.[6] To be sure the number of calories necessary for a male adult weighing 55 kilograms, and performing light work, varies theoretically from 2,000 calories in hot seasons in hot climes to 3,000 in cold seasons in cold climes. Taking into account regional differences the following food standards may be adopted for India.

			Proteins.	Fats. (In Grammes)	Carbo-hydrates.
1	Western Standard ..	3,500	100	90	450
2	Northern India ..	2,400	85	60	605
3	Bengal and Southern India.	2,000	75	50	472

In different regions, the energy required for the maintenance of body-heat and work varies. The weight and stamina of peoples in different regions also are features of adaptive selection. Much of this selection depends on the nature and kind of food, whether, for instance, starch or protein preponderates, or, again, whether durable or perishable; these differences depending on the characteristic flora and fauna of the respective regions. In the struggle for survival, the dietary is possibly adapted to the requirement of the highest output of work on the basis of recoupment with the least waste of botanical and zoological resources of the region. Thus the level of nitrogenous equilibrium of a people is adapted to the supply of exhaustible resources and physiological requirements of work and recoupment in the climate. All this brings about an adjustment of the digestive process, a metabolic

(6) *Shiroshi Nasu*: "Population and Food Supply in Japan," *Problems of the Pacific*, 1927.

balance of the region on the basis of equilibrium between normal output of energy and restoration in a given environment. That the level of nitrogenous equilibrium of peoples differs is now clearly understood. It has been found that, among Eastern peoples, whenever the nitrogenous element is increased, there is increase of foecal nitrogen. No doubt, both for meat as well as for vegetable proteins, there is greater assimilation of nitrogen among Europeans than among Asiatics. In India clinical researches tend to show that the level of protein consumption, which is sufficient for healthy subsistence and normal efficiency of an adult, stands much lower than the same level for the European adult, being 50 to 70 per cent. of the latter's requirements. It is obvious that, in the dietary, there are two needs which are to be satisfied, *viz.*, the nutritional and the energy needs of the body. If, in the system of diet that prevails, a race depends more on carbo-hydrates than on proteins for the energy needs of the body, there is a tendency for the nitrogenous assimilation to suffer. As a result, whenever an excess of nitrogen, obtained from meat or vegetable proteid, is introduced into the body, its assimilation is poor and there is an increase of foecal nitrogen. This will not occur in the case of a people which depends chiefly on protein for the energy-giving function.

COMPARISON OF FOOD CONSUMPTION.

		Grams of protein per man per day.	Calories.
1	Standard requirement for men at moderate work in the Western countries (Atwater).	125	3,500
2	For hard work.	150	4,500
3	British War ration.	175	4,855
4	Average man (Royal Society Food Committee).	100	3,390
5	Fourteen families in York, wages under 26s. (Rowentree).	89	2,685
6	Twelve labourers' families in New York (Wilson).	101	2,905
7	For light work in Japan (Oshima).	100	3,000
8	For hard work, Jinriksha-man (Oshima).	158	5,050
9	Twenty middle class families in Shantung (Adolph).	111	3,355
10	Artisan families in Bengal.	40	2,283
11	Bengal prison diet (McCay).	93	3,500
12	Standard military ration in Baroda (Mrs. Strong).	86	2,400
13	Standard Army ration in Baroda for followers.	86	2,077
14	For muscular agricultural work in the United Provinces.	100	2,400

Chittenden's figures of the nitrogen metabolised per kilogram of body weight may be compared with Voit's, McCay's and Oshima's figures as follows. To these have been added figures obtained at the Physiological Laboratory, Lucknow University.

Bengalis and Oriyas (rice diet largely)	..	·116-·120
Chittenden	..	·120-·130
Biharis and Eastern Bengalis	..	·140-·160
Japanese poorer classes	..	·177
Nepalese	..	·180-·250
Sikkim Bhotias	..	·250
Average European	..	·270
Tibetan and Bhutan Bhotias	.	·350
Nepalese Bhotias	..	·420
Average European in India (McCay)	..	·224
United Provinces peasant	..	092
" middle class	..	·140
" factory-hand	..	·100

MODIFIED VIEWS ON DIET.—Since the investigations[7] of Chittenden and Hindhed the conviction has gained ground that the number of calories which had formerly been considered necessary for a good working diet was much too high. Above all, the quantity of proteins could be reduced to almost half that which was formerly considered indispensable. In Germany it was estimated during the war that the population was overeating to the extent of 59·7 per cent. calories and 44 per cent. in protein. When rations in all the armies had to be restricted, the suggestions of physiologists were carried out in practice, especially among the Germans, whose aggressive and resisting powers were not affected thereby. In America there has been of late a reduction of the consumption of meat and beef, as is shown in the following table:—

Consumptions of Meat per person.

		lb.
1907-12	..	149
1921-26	..	143

Consumption of Beef per person.

		lb.
1907-12	..	71
1921-26	..	61

On account of the pressure of human population domestic animals per acre have been reduced to some extent, and there is a tendency towards securing a better, and

(7) *Castellani and Chalmers*: Manual of Tropical Medicine.

probably more healthful, balance between vegetation and animal food.

It will thus appear that dense populations in India and China being always on the border of scarcity or famine, have through a process of trial and error arrived at a dietary which excludes the overeating that characterises peoples of newer regions.

All this implies that the factors which govern population capacity cannot be understood unless we know the calorie needs of the population on the basis of a comparative investigation into the dietary of different peoples. Comparative dietetics is, however, too recent a study to help the economist who wants to deal scientifically with present and future food-supply.

ECONOMIC STANDARD OF LIVING.—It is not the standard of dietary which makes the pressure of population; it is the standard of social and industrial living as a whole. There is established a reciprocal connection between types of vegetation and dietary and racial peculiarities, all being governed by climate. There is a balance between the expenditure of energy in the normal type of labour necessary to secure subsistence and the energy-giving value of the food of the people. Both the normal food and type of labour react on a people's bodily and mental characteristics; and, in the process of adjustment of race and region, that racial type probably succeeds which shows the largest output of work with the least dissipation of energy from the inorganic and the organic world. There is a good deal of misconception as regards the low standard of dietary of the Indians, Chinese, or Japanese, which will be dispelled by the realisation that dietaries vary not only according to different densities of population, but also according to climates, according to types of labour in which the large or small muscles are implicated, according to heights and weights of peoples, etc.[8] A recent investigation of the dietaries of industrial workers in Cawnpore and their calorie yields has shown that the calories per day per adult worker were

(8) Mukerjee: *Regional Sociology*, pp. 59-60.

nearly 2,000. With every rise in the economic grade the diet yielded more calories. On the whole, the Indian worker in the factory not merely requires, but also obtains, more calories than are needed by the Indian peasant or a professional man engaged in a sendentary pursuit. Thus the calories per adult worker of the lowest grade (2311) are much higher than the estimate of calories needed for a professional worker or a peasant calculated from a study of the latter's basal metabolism. On the other hand, the diets often show lack of balance while the calories which these yield hardly reach the level at which the British working man's diatetic position ordinarily stands. The following comparison is significant.

	Basal metabolism. Calories	Diet.
British working man ..	1,700	3,500
Indian working man ..	1,200	2,400

The former has a surplus of 1,800 calories to expend on bodily movement (including his work) while the latter has 1,200 calories only. A part of this difference is accounted for by lower weight, but the difference indicates not merely less stamina and more apathy, but also less strenuous work. It has been found that the expenditure of calories increases three times when the rate of working is doubled. Both climate and physiological adjustment have fitted the Indian factory hand to work at a moderate pace; if he has to labour unremittingly and strenuously for long hours, he adjusts himself by occasional idleness as well as absenteeism. There is no doubt that work under factory conditions, both in India and in England, demands similar expenditure of energy and its recoupment. It is true that the warmth of the climate does not require heat production to off-set heat loss, as in the Western countries, but on the whole the pressure of unremitting work in standardized production in the factories cannot be maintained for long on a diet which is physiologically inadequate. This is responsible to no small extent not merely for industrial inefficiency, but also for greater absenteeism and prevalence of disease and mortality among the factory workers in our country. But, however much the oriental

workers are under-nourished, it is apparent that the Western nations are overfed to the extent of 33 to 50 per cent. Again, a scale of consumption of raw materials of industries, of fuel, wood, paper and the metals, which has no reference to the resources of the region, must inevitably be unstable and lead itself to an exploitation in other regions irrespectively of their soil conditions and possibilities, or to their adaptive rotation of crops. The world economy has been upset to-day mainly as a result of the irresistible demands of high social and industrial living of a fraction of humanity, which is mobilising the human and the natural resources of the tropical and the sub-tropical world for its own benefit. In a future adjustment of population to resources the lesson of human biology that man's expenditure of nature's store must not exceed what he gives back to it will not be disregarded, and no standard of living will be tolerated which may be based on any improvident use of resources in men and materials, anywhere in the world.

STANDARDS OF EAST AND WEST.—The standard of living of populations of Europe and America has been artificially supported during the last fifty years by their dependence on the raw materials of the industrially backward regions, while coal and fuel as well as metals and other minerals are being exploited, so rapidly that a lower standard of living is anticipated at no remote future. Jevons' dismal prophecy about the coal reserves of England which, according to his estimate, would not last beyond this century, has been followed by other anticipations based on a careful analysis of the world's resources in coal, iron, petroleum, gas, water-power, steel-making minerals, and chemical and structural materials. All these vividly bring out the fact that the rate of consumption of such resources has tremendously increased in recent decades, and that unless the rate is slackened the prosperity of the industrial nations will be eclipsed by that of the agricultural nations. Along with the improvident use of natural resources the Western nations have neglected agricultural production. While in the congested countries

of India and China the danger of overpopulation arises from the fact that agriculture is crowded and industries are neglected, in the West the tendency is quite the opposite. In England, Germany, France and Italy there has been a lack of balance between different occupations. Indeed, it is the congestion of workers in the industries, due indirectly to the standard of industrial living that has been adopted, which has led to the danger of overpopulation threatening the West. It is the rapid urbanisation and industrialisation in Europe and America which have upset the adjustment of population to resources. The neglect of agriculture for industry, unemployment, emigration, and the growth of overseas markets, have gone together. In most of the Western countries the proportion of agricultural workers has been on the decline. England and Belgium depend mostly on foreign-grown food, while all the countries import food and agricultural products. It is true that intensive farming has been adopted, commercial fertilisers introduced, and the land cleaned, drained and scientifically manipulated in the West; but the development of intensive farming has been as nothing compared with that in India, China and Japan, where agriculture has reached the intensity of garden farming or horticulture. This will be evident by comparison of the size of the average agricultural holding in Western and Eastern countries.

Country.		Average holding. Acres.
United States	..	148
England and Wales	..	67
France	..	93
Germany	..	92
Holland	..	87
Japan	..	5
China	..	3¼
India	..	3

SIZE OF HOLDINGS, EAST AND WEST.—Professor East has estimated that a minimum of 2½ acres of land per capita is necessary for the nourishment of man. A recent estimate, based on the standards of dietary and cultivation in the United States of America fixes 1·5 acres of land as the indispensable minimum for "adequate diet

at minimum cost." In India, if we subtract the land utilised to supply overseas markets, we find that what remains does not represent more than two-thirds of an acre per head of population.[9] In 1911 the total population in British India was 240 millions; while the net area under crops was only 216 million acres. The figures for 1934 were 232 million acres for 293 millions of persons. Thus the total cultivated area diminished from 0·9 to 0·79 acre per head of population. In 1911 the acreage under food crops per head of population was 0·81; in 1934 it diminished to 0·70. In the wheat and millet-growing areas of Northern India holdings of about 10 to 12 acres (irrigated) can maintain a family in some measure of comfort, while in the rice areas of the Ganges valley 2 to 4 acres would suffice.[10] In China, in the northern wheat and millet areas, about 4·7 acres, and in the rice-growing regions of the Yangtse delta about 1·7 acres would support a peasant's family.[11] In Japan there are about 5½ million farmers who on the average, cultivate only 2·45 acres of land, a piece, and these constitute 53 per cent. of the total number of households.[12] In Java people are actually living on an average of a fifth of a hectare (say, half an acre) per capita for rice. Of course, they import rice, but not to more than ten per cent. of their production in bad years. And rice is not their only food.[13]

In the United States, the average holding is roughly 50 times the size of a holding in China or India. Again, in the United States human labour does not constitute over 3 per cent. of the power used in farms, while in China half the power is human labour. Horses, mules, and tractors are in use over a surprisingly small portion of the year; while in the East, owing partly also to warmer climate, human labour is kept employed throughout the year. In the rice areas of the Ganges valley, a man culti-

(9) Holderness: *Peoples and Problems of India*, p. 14.

(10) Mukerjee: *The Rural Economy of India*, Chapter III.

(11) Roxby: The Distribution of Population," *American Geographical Review*, 1928.

(12) Shiroshi Nasu: "Population and Food Supply in Japan" in *Problems of the Pacific*.

(13) *Proceedings of the World Population Conference*, p. 98.

vates unaided his holding of at least 5 acres, while in the wheat-growing region he can cultivate 10 acres. In China, 2 acres per farm or one acre per farm in the rice regions, and twice as much in the wheat and millet regions, seems to be the average amount of land that can be spaded and cultivated by the farmer and his son hired man within the time permitted by the progress of the seasons.[14] Human as well as horse, mule, or bullock power is employed on an arranged succession of crops throughout the year in the East, in which the cultivation of legumes, peas, etc., supplies useful fodder and renovates soil fertility.

IMPROVEMENTS IN FOOD CROPS AND DIET.—It is obvious that dense populations in the East have learnt not only to toil harder, but also to conserve both food and soil resources better than the peoples of Europe and America. Yet there is great scope in the East for improvement both in food crops and in diet. (1) The preponderance of rice in Eastern diet should be reduced. (2) A mixed diet composed of wheat, rice, barley, maize or millets is bound to be better-balanced than a diet based on only one staple, *e.g.*, rice. Amongst the poorer peasantry, *bajra* and *juar* are consumed instead of wheat, and since the former are much poorer in nutritive value than wheat, the diet is deficient. (3) The preponderance of carbo-hydrates in the form of wheat and sugar should be reduced, and the digestibility of protein elements of the diets improved. It is often found that the vegetable protein, *dal,* is not easily assimilable and causes fomentation. The addition of milk and milk products in various forms is a much-needed improvement. (4) The conservation of fisheries and greater use of fish as a principal article of diet are also indispensable. (5) A greater dependence on vegetables and on fruits would diminish the demand for rice, or for wheat. (6) The quantity of fat is often very inadequate, although the conditions of hard field labour make this element of diet of paramount importance. (7) The extension of the white potato or sweet potato would give a greater yield of starch per acre than is secured from rice.

(14) O. E. Baker: "Land Utilization in China," *Problems of the Pacific.*

(8) A great deal remains to be done in the directions of scientific storage of grain, of refrigeration of fish, meat, dairy products, etc.

AGRICULTURE IN EUROPE AND AMERICA.—It is estimated that potatoes will feed 420 persons per 100 acres, while grass, turned into beef, will feed only 15.[15] Simon reckons that, after the introduction of intensive horticulture, France could easily feed from two to four times of her present population. In England the Board of Agriculture has recently pointed out that information, made available by research and experiment, is sufficient to show that the number of cows which can be maintained on the produce of a given area of land is from two to three times greater when that land is under the plough than when it is under grass, and that is possible for a small holding of from 15 to 25 acres to be made an economic undertaking.[16] For several generations Europe has been practising a system of agriculture which must be characterised as improvident as compared with the system prevalent in India and China. In most parts of Europe the land is not naturally fertile. The system of land tenure also has tended to reduce farming efficiency. For a long time past the different types of agriculture, the three-field system, grass husbandry, etc., have been adopted more and more to capitalistic development. This is especially the case with the newest form of agriculture, which is influenced rather by the state of the market than by an arranged succession of crops. In the temperate zones, the predominance of industrial and manufacturing enterprise has led to the neglect of home agriculture, and to dependence on the raw materials and foodstuffs of the tropical regions or other less developed countries which are more fertile, or where the food production is above the normal requirements of the people. It is only in Belgium, Germany, Denmark, and France that we find the triumph of scientific agriculture. Both in North and South America agricul-

(15) See *The New Statesman*, Vol. XXII, p. 538 (February 16, 1924), quoted by E. A. Ross in *Standing Room Only*, p. 195.

(16) Mukerjee: *Rural Economy of India*, p. 201.

ture is less careful of soil resources and the interests of future generations than in Europe. It has been estimated that one ox eats as much as five men and requires five times as much land for its support. It has also been calculated that an ox represents 150 days' rations for an Argentine cowboy *versus* 10 years' rations for the Easterner. A physiological table of food values shows the sufficiency of vegetable food. Thus the luxury of meat consumption is indulged in the new countries by a most wasteful utilisation of space. On the other hand, densely-peopled countries which cannot afford reckless exploitation of the land maintain far more numerous dairy cattle, which also enrich the soil by returning manure to it. In the East the dense populations can be maintained only by the essentially vegetarian diet and the omission of stock raising. Even in the West dense populations will inevitably find meat become scarce, in spite of more intensive agriculture, and have to depend increasingly on meat imported from countries which are sparsely inhabited and have adopted reckless methods of soil exploitation.[17] When four persons support themselves respectively on a 2,000-acre ranch, as in the American West, or on a 160-acre farm, as in Canada, or on a 20-acre farm, as in France, or on a 2-acre garden-farm as in China, Japan and the fertile parts of India, there is no questioning the fact that the Chinese, Japanese, and Indian type and conditions of cultivation are essentially superior.[18] In America, if sufficient humus is provided, by the ploughing-in of plant roots, leaves, manure, etc., and the soil is not allowed to wash away, agriculture, with crop rotation, may continue on the same fields for indefinite periods, as in parts of Europe and Asia. The violation of these simple rules of soil preservation already, in a few decades, has brought irreparable ruin to many American fields, especially in the South-Eastern states. The keeping of live stock is the type of agriculture which best preserves

(17) Mukerjee: *Rural Economy of India*, pp. 200-201.
(18) Russell Smith: *Industrial Geography*, p. 40.

the soil, because it permits the return of manure to the land and thus tends to maintain fertility.

POPULATION AND BALANCE.—The problem of releasing the pressure of population is the problem, then, in the first place, of finding the right balance between different kinds of labour, between manufacturing and extractive industries region by region; and, in the second place, of finding out an optimum for the region adjusted to an art of living that is based on a fair and equitable distribution and provident management of the resources of the world. The questions of economic exploitation of the backward regions, of colonisation and emigration, are subsidiary to the primary considerations of the adjustment of human skill and plane of living to the resources of the region which has nurtured the people and given it its material framework. Much of the jealousy, suspicion and unrest among the peoples of the world due to restrictive emigration policies or the harsher features of economic imperialism will be avoided if there be a frank and free recognition of the imperative necessity of distributing the population of the world, not from any imperialistic or national standpoint, but from the wider considerations of world economy.

CHAPTER XIII.

ECOLOGIC LAWS: UNITY AND ORGANISATION.

SPATIAL GROUPING AND ACCOMMODATION OF DISSIMILAR SPECIES IN THE REGION.—The conception of the natural area or region, which plant and animal ecology has given us, has proved fruitful in the classification of social and cultural types.

Natural regions are found to be not merely geographical but also social and cultural entities. The social processes can, therefore, be best understood if we proceed with a preliminary ecological classification of social types. As biology received a great impetus after the systematic surveys of plant regions and faunal realms had commenced, so has sociology gained in realism and in the use of quantitative methods with the emphasis of certain fundamental social types and stages, which are the outcome of the cumulative effects of environment and ecologic succession. As the natural area has become the unit of consideration in sociology, so the explanation of social phenomena in terms of the spatial and temporal distribution of the activities of individuals derived from ecology, bids fair to widen the scope of concrete social measurement. Further, besides the importance of position, distribution and movements of individuals in space as explaining social processes and the importance of the spatial grouping and adaptation of individuals and social institutions to regional conditions and their mutual give and take within the limits of a natural region, the principle of balance of species living in the same region also forms a valuable contribution to the study of sociology.

Ecology has broken up the simple and undifferentiated homogeneity of the living environment and brought to the fore the interaction of the different species as well as stages of development of organisms.

In each natural region, ecology shows us, the life-community has a unity and individuality of its own; each consists of diverse species which fit themselves to others for the common task of exploitation of resources by which the subsistence of each and all is assured. In the plant world the forest trees, mosses and lichens, grass and shrubs live close together without competing for the same nutrient elements, and even contributing to the welfare of others. Each plant and animal species practises its own peculiar economy, which impinges on the economy of others in a system of reciprocal competition and dependence, with typical space distributions of the inhabitants. Different species of plants and animals thus form themselves by reciprocal adaptation into an organisation, however unstable it may be, and the life-community undergoes evolution as a whole in a given habitat.[1] This idea of a balance of diverse species, though a temporary and shifting balance, has compelled recognition in all sciences of life, and the biology of human communities can no longer stand aloof from it. For human communities are an integral part of the organisation of life in the region; man, in whom life attains its greatest variety and intensity, is the focus of activities which radiate out in linked chains to the minutest and most primitive of life's communities; while he himself is enchained by conditions and circumstances which serve, interpenetrate and overreach him and his ends. In the swaying balance of the region, man and his works and institutions are equally implicated.

DOMINANCE IN THE ECOLOGICAL COMMUNITY.—Social ecology thus emerges as a new and important division of sociology. Its task is three-fold; first, to trace the adaptations of interacting human beings and of interrelated human institutions to the region, including in the latter term not merely climate, soil and land, but also plant and animal communities. Secondly, to investigate the spatial and food relations in which human beings and activities are organised in a natural area in terms of the

(1) *See* Elton: *Animal Ecology and Evolution*, Ch. I; and Wells, Huxley and Wells: *The Science of Life*, Book VI, Ch. V.

ensemble of ecologic forces; and thirdly, to measure the balances and mutual pressures of human communities, along with other living and non-living communities, in the region, and to discover whether these prove favourable or unfavourable for man's dominance and permanence. In the natural region uninhabited by or uninfluenced by man and his domesticated animals, the dominant plant-communities, which are pioneers in exploiting the environment, determine the character and succession of animal communities. In pristine conditions many large and small animals range over the largest plant communities, while others are confined to minor variations. All are intimately woven in with the plants and with many interdependencies of cross pollination, food, soil shifting, etc. Thus the geographical distribution of many of the plant and animal species which make up the assemblages are in general correspondence. Mammals and birds usually are most important in biotic communities, even where considerable changes have taken place in the region. Then follow in the order of their importance insects, lower land vertebrates (chiefly reptiles) and lower invertebrates. Prof. Shelford remarks: "From the standpoint of ecology, it is not correct to refer to this as the age of insects, for it is in reality the age of mammals and birds. Referring to man's conquest of nature, it becomes the age of man and insects. These are most important in secondary, especially agricultural communities."[2]

LACK OF UNITY AND BALANCE IN THE MAN-MADE REGION.—In an agricultural region where man has lived for centuries and reared his flocks and herds, Nature's climax is thus altogether supplanted, and we have dense and even unnatural agglomerations of new plants (crops), animals (live stock) and insects and bacteria side by side with the massing of men over great stretches of land. The region, man-made as it is, often slackens the vital circulation due to man's conscious or unconscious interferences with the slow and subtly interwoven processes of Nature. Thus the forest communities increase the

(2) V. L. Shelford: Some Concepts of Bioecology, *Ecology*, Vol. XII, July, 1931.

equability of temperature and make not only the climate but also the region more favourable for man by preventing flood and drought, conserving the subterranean reservoir of water, and enriching the soil by the accumulation of humus. The unchecked destruction of forests as human settlement progresses proves detrimental not only to many large and small animals but also to agriculture and conditions of artificial irrigation, in short to man's permanent economic prosperity. As a matter of fact in ancient areas of human settlement man, like a spendthrift, always draws upon Nature's reserves of capital and energy without replenishing these for the future. Unchecked in numbers by natural enemies, which keep down the numbers of animals to a normal level in an over-stocked region, man multiplies beyond the limit which the ecologic balance and rhythm of the region permit.

With the continuous multiplication of population, man's intensive agriculture spreads far and wide, the trees and grasses being replaced by a variety of food plants massed together both in time and place. The cause of the accelerated erosion which has become so great a national problem is the destruction of the native mantle of vegetation, as Lowdermilk points out, through fire, destructive lumbering, heavy grazing, railroad and highway cuts, clearing and cultivation for agricultural crops. The activities and reactions of organic life, including animals on soils, are undoubtedly for the most part beneficial. In proportion as animals increase the absorption of water by soils, promote favourable soil conditions for the establishment of vegetation cover, and assist in the process of scattering and planting of vegetation, they tend to prevent erosion. Breazeale stresses the opinion that the results which man obtains with fertilizers are indirect, that is, man fertilizes the soil flora and probably the fauna, and not necessarily the crop. There is a weak link in every chain and in many a unproductive soil the absence of fauna may be the weak link. Animals certainly bring life and vitamine-like substances into the

soil. As Marsh says, "Every plant, every animal, is a geographical agency, man generally a destructive (element); vegetable and, in some cases even, wild beasts restorative powers." The soil is inhabited by a significant community of plants and animals which under natural conditions work together to form a rather harmonious and productive whole. But many things can happen. Disturbance of the structure of soil, removal, in any manner, of a part of its organic inhabitants or the addition of others, alteration in the water content and in the chemicals associated with such processes as irrigation, evaporation, drainage, or fertilization, are certain to modify the soil. Under suitable conditions the soil becomes even more productive than it was originally, temporarily at least; under others it is depleted through actual removal of material or some other form of impoverishment. Burger, with good reason, compares the agricultural soil to an unorganised mass of building material, whereas the natural forest soil with its definite, stable organisations is like a house built from this material. It is becoming more and more generally recognised that a natural soil, like a living organism, must be studied as a whole to get a correct idea of its responses.[3] As man eats or removes crops from the land in quick succession without replacing its mineral constituents, the natural soil is impoverished; while his encroachment on grasslands and forests and the drain on the subsoil water reservoirs upset the vegetative and hydrographic balances of the region. The soil gradually decreases in its water holding capacity, food and shelter become dearer for animals, while an alternate sequence of disastrous floods and droughts or a gradual desiccation may also follow. In the succession of living communities in the region we find that the types become progressively richer and higher and make greater and greater demands upon it. But when we reach man his manifold and specialized exploitation knows no bounds. Man continually strips the region of trees and grasses, fertility and moisture, there-

(3) W. P. Taylor: Some Animal Relations to *Soils*, *Ecology*, April 1935.

by making the lives of later generations ever so much more strenuous and precarious.

As he congregates in mass and forms crowded rural settlements and cities, he also gives an open invitation to insects and parasites which bring about plagues and epidemics on a scale unknown to primitive society. Insects destroy not only man but also his food and materials. The mere massing together of a particular kind of crop and domesticated animal contributes to the multiplication of pests and the spread of various animal and plant diseases, unknown to backward agriculture. Defective soil aeration due to constant tillage of surface layers necessary for feeding a multiplying population affords new facilities for the propagation of fungi which damage crops, and create dead alkali lands on which crops cannot grow. An onslaught of herds and flocks often more concentrated on particular areas than their wild prototypes even were and continued for generations cannot but lead to the deterioration of vegetation thereby facilitating the rapid denudation of soil which it has taken long ages to build up. Grinnell has shown that "close stamping tends to exclude the air and hence to suffocate the plant roots, to which oxygen is as essential as it is to animal life." Field erosion continued for a long time creates wild, sterile, ravine lands with yawning gullies and fissures and makes even fertile valleys deserts. With the increase of the run-off of water and of erosion the fertility of soil decreases both in the hills and in valleys, while the streams become broader, shift more and become more torrential, acquiring greater erosive and carrying power. River floods thus become more frequent and destroy crops and human settlements.[4]

MAN'S RECURRENT FAILURE THE RETURN OF THE PRISTINE FOREST.—Not merely are the components of fertility of land, and the constructions and devices of man washed into streams and rivers, but the waters themselves being full of mineral matter obtained from the soil cap of the mountains and richer valleys become detrimental to agriculture. Fisheries similarly decline, this being due to

(4) Mukerjee: *The Rural Economy of India.*

the destruction of forests as the ashes resulting from forest fires kill fish in the rivers that drain such denuded areas. In the lower valley the silting up of rivers deprives the country of the red water it formerly used to receive. The cessation of flood irrigation and natural drainage leads to the decline of agriculture and to the spread of malaria, which slowly but progressively devitalises the human community. Thus a once fertile and productive land is exhausted and can maintain only anæmic crops, cattle and men, its water-channels choked with weeds, its ancient house sites covered with jungle and its thick population stricken down with disease. The forest now re-asserts itself in the full tide of its natural increase where once prosperous cities, villages and fields flourished.

The region which may have favoured the early growth of civilisation by offering man the largest free gifts, now becomes niggardly and frowns upon him. The progression of inhabitants in the region, one set of plant and animal community following another in regular sequence, receives a set-back as man dominates and persists in a one-sided exploitation; and in fact man's disregard of chains of disturbance bring both himself and his surroundings to common ruin. Of all animals man has failed to plan his effort and food supply as a species on a continuing basis, and the appellation of *Homo Stultus* is nowhere more applicable than in those rich regions laid waste after a few generations covering the era of his brilliant and wasteful achievement, namely, civilization. The return of the forest, which would now represent the stable climax of the region, marks the complete failure of men on the land.

It is the meticulous study of a definite natural region which alone can bring out the subtle and multifarious connection between human efforts and numbers and the exigencies of the region, and thereby help towards making social ecology a science.

MUTUAL ACCOMMODATION OF SPATIAL, ECONOMIC AND SOCIAL RELATIONS.—Most living organisms form themselves into associations, colonies or communities. In

fact the economic activity of multitudes of dissimilar living creatures in a region, each living in amity with some of its neighbours, but in competition with others, may be expressed in terms of their individual numbers, which, in the case of the human community, we call density of population. Social ecology is thus the comprehensive science of the balance of the human species in a natural area studying the physical and biotic factors which affect the pressure and distribution of diverse species of plant and animal (including human) associations. Social ecology recognises four fundamental ecological processes: distribution, invasion, succession, and mutual accommodation in the ecological complex. The geographers have been for a long time studying the physical factors which govern the distribution of population on the world's map. The economists have added to these studies an investigation into the causes of the localisation of large scale industries and the effect of modern forms of transportation and communication, as well as emigration, as governing the concentration of population in special regions and zones. The social ecologists have now come to study the social composition and characteristics of population in different zones of human settlement. Thus the difference in sex and age groups, one of the most significant indexes of social life in the zones of human concentration and dispersal, is now being investigated with reference to various social phenomena. As between villages and cities there is striking difference everywhere in age and sex distribution. As a rule the percentage of adults and immigrants is much higher for cities than for rural districts or for the country as a whole. Again, cities contain a mobile, floating population, and exhibit a striking disparity in the proportions between the sexes. The economic and commercial factors which lead to industrial specialisation also tend to create single sex regions and cities. The coal and heavy industry cities and regions show a striking excess of males over females. Similarly, textile cities and regions and certain plantations exhibit an excess of females over males. In great cities the divergence in manners,

in standards of living and in general outlook of life, in different urban areas, has been carefully studied by Park, Burgess and others. Every typical urban area is likely to contain a characteristic selection of the community as a whole, representing distinctive social habits and standards. Thus, through the processes of social selection and segregation of the population, each natural area, whether a region or a distinct urban area, in a great city becomes the habitat of a natural social group. Backwood clearings, and lumber camps, mining settlements and plantations contain a characteristic selection of the population of the country as a whole. Thus there are regions in the country where the pioneer woodsman, the squatter, the immigrant and the coolie dominate; in ancient village settlements the number of old persons and of women and children is relatively high; in the frontiers of cultivation there is striking preponderance of men, and the families are nomadic and disorganised. Each such region develops characteristic traits and attitudes of the social group. The mobility, the irresponsibility and shiftlessness of the *coolie* and the cottier may be contrasted with the stay-at-home habit and attachment to the farm and the homestead of the peasant in the village community. There are regions where the collective management of irrigation and a crop of collective agricultural customs and usages favour social cohesiveness. Rice with its demands upon collective management of water-courses and embankments and upon participation of the young and old in field operations, nourishes not only the teeming millions of the east but their characteristic village communal and patriarchal family organisations.

There are agricultural tracts where a money-crop like jute or cotton, which fluctuates in prices, favours an intensive individualism, extravagance and a speculative spirit which infect everybody from the small cultivator to the big wholesale merchant. The plantation, with its rule of overseers and the approximation to factory methods, is associated with a steady, unremitting drudgery which is in striking contrast with the seasonal fluctuations of

labour, wealth and social activities associated with arable farming. Monsoon agriculture in particular is characterised by a well-marked division of the agricultural seasons and the seasonal cycle of social activities. Both the routine of agriculture and the social activities and attitudes are modified where well and canal irrigation secure the peasants relative freedom from the alternate periods of hyper-activity and idleness imposed by the cycle of the seasons.

It is in this manner that the isolation or aggregation of the rural settlement in the jungle and the marsh or in the closely packed river valleys, the seasonal routine of agriculture as imposed by nature or as modified by man, the kind of cropping or the particular combination of plant and animal industries or, again, the conditions of proprietorship and tenancy in a given area—all these largely govern the attitudes, social activities and inter-related institutions of social groups. On the other hand, social selection would tend to favour social attitudes and institutions most suitable for the exploitation of natural resources and increase of human numbers. Thus along with crops and agricultural practices, social attitudes and institutions invade new appropriate areas—leading to a more favourable adjustment of spatial and social relationships. Through a gradual adaptation of spatial, economic and social relations man ultimately finds a balance, however temporary it might be, with the entire range of ecological forces.

MAN AND THE CLIMAX VEGETABLE AND ANIMAL COMMUNITIES IN NATURE.—In plant communities we find one or a series of invasions taking place culminating in a particular type of climax vegetation in the area. The middle stages of a sere often show the most active phases in the competition of different species for dominance. Ultimately the climax dominates, enters and gains victory over competing forms. In a similar manner heavier-yielding crop varieties and superior agricultural practices attain dominance and a higher cultural group displaces a lower one. In eroded and colluvial soils of mountain

regions, and in the ravine tracts of the valleys exposed to continuous grazing and browsing of domestic animals, we have a retrogressive succession of vegetation. Such deterioration of vegetation initiates also a new economic cycle in a deterioration of agriculture, a change from intensive farming to cattle grazing, and a general social stagnation due to increase of rural distances caused by fissures and gulleys in eroded areas. There is ultimately a deterioration of the population type corresponding to the vegetative retrogression. All this indicates the significance of the factors maintaining a relative spatial balance in which the fall in the sub-soil water-level, the appearance of thorny xerophytic plants, the disappearance of the larger animals and the decay of agriculture and rural life are equally implicated.

On the other hand, it is the component parts of climax vegetable associations, which indicate the agricultural possibilities of regions as yet untouched by the human hand. Even such a weed as the prickly pear cactus, the spread of which over large areas is regarded as a veritable curse, gradually prepares the social for secondary seres, and the beginnings of dry farming. Man's first clearings in the jungle as well as his skilled and selective farming in fact have utilised the plant-indicators, which are, so to speak, Nature's signals of crop-improvement. But for fuel and timber, for raw materials of industries and for rapid and continuous raising of one crop, man often has played wholesale havoc with vegetation, deforested vast areas and ignored and needlessly destroyed the established linkages of the vegetable environment. It is because of man's deliberate and wilful exploitation of the environment that the bio-economic balance of the region is apt to be easily upset. Man is relatively free from the mechanisms of control which regulate numbers among animal associations. Thus the increase of human population often narrows the structural base within which the ecological processes operate to the detriment of man and his civilisation. Indeed, this makes the process of mutual accom-

modation in the ecological community the most important consideration in human as distinguished from plant and animal ecology. What J.B.S. Haldane has observed discussing the future of Biology is no biological imagination: "One gets the very strong impression that from the quantitative study of animal and plant associations some laws of a very unsuspected and fundamental character are emerging; laws of which much that we know of human history and economics only constitute special and rather complicated cases. When we can see human history and sociology against a back-ground of such simpler phenomena, it is hard to doubt that we shall understand ourselves and one another more closely."[5]

MAN'S CONTROL OF ECOLOGIC PROCESSES.—When man comes on the scene and enters into competition with societies of plants and animals the existing regional balance, to be sure, is modified and controlled to suit his special and growing requirements. In the first place. man frees himself from the natural laws which govern reproduction in the sub-human world. His rate of growth is no longer determined by the chains of eating and being eaten from inside and outside which enmesh the lower animals. Man's numbers are less determined by the climatic factors of his environment and his natural enemies, including parasites and food, and more by factors which are assimilated into what we call the standard of living. Secondly, man selects certain plants and animals for encouragement and destruction with a view to convert the shifting balance of the region in favour of his own multiplication. Even bacteria are brought to man's aid as in the case of soil recoupment by growth of legumes and by use of organic manure, while the biological control of pests and eradication of many diseases are based on the recognition of the web of life or the inter-relation of living creatures. Thirdly, man imports values into the balance of the region. His traffic with the environment bears an indelible impress of his conscious strivings and aspirations. Thus social ecology, though an extension of the

(5) J.B.S. Haldane: *Possible Worlds*, p. 142.

science of life communities, is yet distinctive in its outlook. Lastly, social ecology deals with a dynamic and purposive organisation of life-community. The human habitat is not static but dynamic because of the unique development of social communication and tradition. But all the same, man like other animals sees and finds an optimum density, which escapes both the danger of destruction through chance emergencies and the equally disastrous results of overcrowding and over-eating the food supply. The desirable or most advantageous density of population is conceived in a different manner by man, but there are reasons for supposing that when the human population fluctuates in numbers, there are certain safeguards found in common with most animal communities which prevent ecological disaster. This, however, holds good only in the case of those human communities which by multiplication and absence of migration, have reached almost the ultimate stage of exploitation of the natural resources of their region.

MAN'S DEPENDENCE ON ECOLOGIC LAWS.—For man is naturally a slow breeding animal and his standard of living as contrasted with the standard of subsistence ensures a low fertility. But both the vagaries of man's chemical and physical surroundings and of social traditions may emphasise his fecundity disturbing the rhythm of the region and the composition of its diverse species or communities. By indiscriminate multiplication unconsciously encouraged by social suggestion and culture and conservatism, which attaches him to the land and the homestead, man, who has separated himself from the brute creation, is once again dragged down. An unrelenting economic pressure brings about a close adjustment of his economic habits and practices to climate, food and resources; he becomes, like an animal, a creature of the region, limited by the iron laws of a physical and chemical environment and the elastic but often more complex and fateful laws of his biotic environment, (Elton). Under such circumstances, brought about by factors in man's social environment rather than by heredity, man thus

once more shows a dependence upon the ecologic laws which govern the numbers among species of plant and animal associations, and the population problem reverts to an ecological problem. Sunlight, temperature, humidity, rainfall and soil govern, through agriculture, and food-supply, the population balance and density. When these latter depart too far from the optimum balance and density, and the same ecologic agencies of epidemic, famine and decrease of vitality which reduce numbers in the animal community, come to operate, it is through the operation of the internal and external ecologic factors that the human community is enabled to adjust itself to the fluctuation of circumstances. Each such adjustment accompanies a change in the spatial distribution and movement of individuals, their spatial and food relations and the spatial adaptation of social relations and institutions, society assuming that pattern which can react upon the region with the maximum of energies left over after the solution of its inner conflicts and adjustments. The organisation of life in the region, including society, thus acts as a whole; and, indeed, both life and the region, equally growing and fluent, cannot be regarded as separate factors, but have a unity in a specific normal pattern which is actively maintained through linkages, organic and human, binding the Kingdom of Nature in all its parts to the Kingdom of Man in all its extensions.

CHAPTER XIV.

ECOLOGIC LAWS: DOMINANCE AND SUCCESSION.

THE MOVEMENT OF LIFE COMMUNITIES.—Sociology will gain more in realism, the more its methods approximate to those of plant and animal ecology. Social phenomena and processes can be interpreted in concrete terms of the spatial and temporal distribution of the activities of individuals and associations, which is one of the central ideas in ecology. Human geography, indeed, took up the idea of the spatial grouping and adaptation of institutions to the features of the landscape long before the ecological outlook came into prominence.

O. Schluter, for instance, thus defines the interrelation between population and landscape: "In human geography we shall discover that in the realm of human activities there is no lack of objects, which belong as properly into the landscape as do forests and meadows, rivers and mountains. Primarily we are concerned with visible corporeal objects. Man is considered in addition to his work, not as individual, but in his varying expressions of population density, visibility and tangibility of the objects is, however, not sufficient. In addition they must have significance in the composition of the landscape. They must have, therefore, a certain areal extent or must be capable of being composed mentally in areal terms." The quantitative study of plant and animal associations and their spatial and food relations, pursued by modern ecologists is, however, much deeper and more precise than the anticipations of the landscape geography of the German School, and bids fair to throw unsuspected light on the biology of population growth. The study of plant and animal numbers gives us the fundamental laws governing the distribution of human populations, the conditions of maintaining population balance and optimum and the biologic consequences of deviations

from these. Besides the ecological treatment of human homes and occupations, and larger human hives, their industries, movements and achievements, aids towards a better understanding and conservation of nature and life in evolution, of decline, of development as well as survival, organic and human.

Man and his works form a part of the area, whose content and individuality it is the task of social ecology to investigate. The most striking fact that emerges in such investigation is the balance, though a shifting one, between man, his presence, the very fact of the existence of population, and the rest of nature. To be sure, such balance is a complex resultant of actions and interactions, which man only partially comprehends but which sweep through him, up and down and all around, bringing the various parts of inanimate and animate nature into one interconnected whole. Man's doings reverberating through nature, however, often produce, instead of harmonies, disturbances, which redound to insecurity and sometimes to the ruin of his generations. Social ecology reveals how in crowded regions the unconscious or wilful disregard of regional balance, the result of population pressure, may ultimately lead both man and his habitat to a common doom. The conditions of the maintenance or disturbance of regional balance in fact form a theme of great practical interest in social ecology. Social ecology, indeed, exhibits not merely Nature's gifts but also her reprimands, which man himself invites by his own thoughtless disregard of the intertwining of the vital threads. Thus the quantitative study of plant communities and animal aggregations forming harmonic patterns in the web of life would show man the dangers of population pressure as it overstrains or snaps the vital threads. Plant and animal ecology indicates that if the numbers and claims of human associations are in discord with the system or organisation into which the ecological community evolves through long-established linkages, Nature sets in motion certain processes found in common with most plant and animal associations which prevent an ecological calamity.

ECOLOGIC CONTRASTS IN THE DIFFERENT STAGES OF THE VALLEY.—The Ganges Valley is a most interesting region from the standpoint of social ecology. It is the most heavily populated plain in the world. The plains of China, which are also exceedingly congested, are far more varied from the point of view of soil conditions and habitability, and the density there is accordingly very unequally distributed. On account of the heavy density as well as a uniform distribution of population over centuries in the past in the Ganges Valley there is no other region over which we can study to the best advantage the spatial and food relations between man and his environment. Such uniform diffusion of population is chiefly the result of the more or less uniform course of the Ganges along its ancient channel through the centuries, carving all the landscape into flat valleys for the aggregation of men. The main river and its tributaries according to their youth, maturity and advanced age exhibit wide valleys and broad flood-plains subject to inundation or broken profiles and narrow valleys intersected by ravines, leading to marked differences in cropping and farming practice. The Ganges itself, though a very old river, shows signs of advanced age in his lower course while in his middle course he is mature and in his upper course still youthful. In his upper and middle courses the work of soil erosion and transport is still going on. In the middle course the destruction of vegetation along the banks due to extension of cultivation and indiscriminate grazing has sometimes made the process of soil erosion more active. This affects both irrigation and cultivation in the riverine tract. In the lower course the level of the river bed and the banks is now above that of the surrounding countries as the result of the process of sedimentation. The flood waters thus overflow the banks in the active delta and cover the country with alluvial deposits. During the flood season the drainage is towards the inland depressions and marshes along successive terraces of rice fields which are irrigated in this manner. Indeed, with the exception of the narrow strip of higher land on either side of the river which is usually densely crowded with

villages the country seems to be almost wholly submerged. But such flooding is indispensable not only for the type of cultivation but also for scouring and drainage. When, however, the flood season is over and the water falls, the movement of water is reversed. The immense volume of water contained by the lateral spill basins during the flood season now gradually flows through every *khal* or channel into the river after having deposited its silt and fertilised the land. All this has important effects upon both agricultural productivity and density of population. Sometimes again a river which has completed its cycle from youth to old age begins its activity over again owing to some earth movement. Such tributaries of the Ganges as the Tiesta and the Damodar, for instance, have changed their courses phenomenally, with consequent effects upon land forms and through these upon agriculture and distribution of population. Thus location and the stage in the development of the rivers and their valleys govern materially the conditions of pressure and distribution of population.

The Ganges Plain, again, forms a tropical region, having a mean annual temperature of over 20 degrees C, that receives the monsoon rainfall. It is the vagaries of the monsoon which determine agricultural prosperity or adversity. The contrast between the dry upper plain where the rainfall is irregular and does not exceed 35 inches per annum, and the delta, which exhibits the world's highest record of rainfall (100 to 120 inches), which never fails, is one of the most vivid in the world's agriculture.

WATER AS THE ECOLOGICAL BASE OF THE HUMAN COMMUNITY.—In the different agricultural regions into which the Ganges plain divides itself water (rainfall, irrigation or flood) operates as the chief limiting agent in agriculture and the growth of human numbers. Soil (old or new alluvium) through its effects on the nature and rotation of crops, is also an important factor determining aggregation of population. The subsoil water level (high in the old or low in a young region) also determines the cropping (dry or wet) and methods of irrigation

and cultivation, and hence influences the density of human numbers. Along with land and river forms, extra-terrestrial phenomena like sunspot and weather cycles have an intimate bearing upon the vicissitudes of man and the distribution of population. Sunlight, soil and water supply thus determine in the long run the concentration and dispersal of human communities. The sun-baked, well-watered plain, with its continuous and uniform cultivation favours the concentration of both people and habitations. The scattered distribution of holdings which tends to minimise the risks of agriculture and distribute soil opportunities equally among a dense population, the construction and maintenance of canals, wells and ponds and the cultivation of the wet variety of rice which demands collective management and distribution of water supply, all contribute to the concentration of rural dwellings. Along the elevated and healthy sites fringing the big rivers, villages are established and thrive by mutual co-operation in agriculture and social life. In the low plains and flooded areas, the necessity of defending their homes against the waters also leads men to form close settlements wherever high places are available. But in the extensions of cultivation whether in the forested region or in the flood-swept *char* and marsh the habitations are scattered here and there, each among its fields and gardens. In the low lands of the delta, the thatched cottage separated from its neighbour with the vegetable garden or fish pond, its orchard of banana, palm and nut trees, and its hedge of bamboo and *madar*, serving as a shade, a defence and a dyke, is the prevailing type. As contrasted with the organised, compact and stable community life in the villages of the upper plains, the isolated hamlets in the lower delta exhibit strong elements of individualism, movement and adventure. Like the shifting nature of the landscape, which is plastic in the hands of the mighty delta-building rivers, the population type is unstable. Man here combines fishing, transport and trade with agriculture. Fearless, enterprising and extravagant, his social habits and interests bear the indelible impress of the hurry and bustle which the

regular sequence of floods and tides imports into the region. There is nothing here of that attachment of the peasant to his home and his fields characteristic of the upper plain which leads him to divide and sub-divide his holding homestead, even his trees, among his children, none of that peasant solidarity, living sympathy and closeness in ancient village settlements. In the delta peasant and fisher communities mingle and clash, homesteads are early deserted and "boom" markets arise with the tide and disappear at ebb. The marsh and the delta peasant lives a life of less economic uniformity. The ecological organisation here is marked by constant and rapid change. Mobility measures the rate of change: social life in the lower delta is characterised by quick change of habitations and occupations, quick transport and marketing, quick movement of population, of land values and wealth and quick change of social "distances".

Man's spatial and food relations are thus seen to assume characteristic patterns according as water, which supplies the ecological base of civilisation, carrying and storing energy for the use of life communities, is utilised and controlled differently by human groups. Geographers now emphasise the hydrosphere rather than the lithosphere in the forefront of their studies, which thus attain a certain philosophical consistency. Civilisation is essentially water-borne and both physical and human geography are concerned with the carriage and storage of energy on the surface of this earth and the vehicle is the Protean element, water.[6] Accordingly as man constructs wells, canals or embankments, as the depth of sub-soil water determines his dry or wet cropping, as his standard of farming is governed by the maturity or immaturity of land forms built by water, or as the fluid movements determine the distribution and movement of population and wealth, we understand water as the *primum mobile* of the growth and development of life communities.

(6) H. J. Mackinder: *The Human Habitat, Presidential Address to the Geography Section at the meeting of the British Association,* 1931.

THE ECOLOGICAL SPATIAL RELATIONS OF MAN.—In the village communities of the upper plain the homesteads expand by mere aggregation and the people are stay-at home and conservative. Social distances are relatively fixed. Occupations and castes are few, simple and stereotyped. Economic changes are counteracted upon by barriers of custom and public opinion. The social position or status of the individual is determined by his social group or caste. It is the latter which largely limits and governs credit as well as the standards of consumption. Land-transfers are infrequent, and values of movable as well as immovable properties change slowly. The increase or decrease of wealth and change in social position proceed at a slow tempo. Where society moves at a rapid pace, individual misfits are more common and crime, vice and other forms of anti-social behaviour are more frequent. In the pioneer hamlets of the delta as well as in fast decaying village communities, crime is equally evident, symptomatic of quick change of social position and distances. Social ecology will, indeed, reveal a striking contrast in the position, distribution and movements of individuals in the contrasted natural areas such as the upper plain and the lower delta. A description and analysis of social phenomena in terms of space and the elementary movements of individuals which social ecology has in view would make it possible for the fundamental logic of the physical sciences to be applied to human relations.

THE ECOLOGICAL RELATIONS OF MIGRATION.—Human spatial and food relations as conditioned by the environment also migrate to appropriate natural areas. Plant and animal ecologists have made us familiar with the concepts of distribution, invasion and succession.

Though most plants must be regarded as sedentary organisms, the migration of plants to appropriate ecological areas is a familiar botanical phenomenon. In fact if we accept the conclusion that each species of plants originally appeared at one place on the globe it is clear that plants are able to migrate far afield. The capacity

of a plant to migrate is closely correlated with the possession of fruits, seeds, or special detachable parts which, by virtue of various structural features or through power of resistance to desiccation, to the effects of sea water or the digestive juices in an animal's intestine, can be carried longer or shorter distances from the stationary parent. "Some plants", observes Seward, "are almost cosmopolitan, and flourish equally well under very different climatic conditions; other have a restricted change and are recorded only from a few localities or a continent or from a single island".[7] Animals and humans, like plants, show different capacities of migration and acclimatisation.

The distinguished ecologist Adams has studied the ecological relations of migrations of animals. The relative freedom of motion in animals has possibly led to an over-estimate of their freedom and to the neglect of those limitations of the environment and of behaviour that together restrain them. Much has been made of physical and geographical barriers, and there is no doubt as to their influence, but the physiological and mental limitations have not been as fully studied. It is only in recent years that the regional spacing of breeding birds has received independent recognition and study, not only by reason of its influence upon breeding habits but also on account of its influence upon succession. That birds which nest in large colonies on the shores space themselves has long been observed, but the fact that a similar but larger unit of spacing applied to the majority of birds during their breeding season was much slower in gaining adequate recognition. Many mammals are similarly limited, such as rabbits, deer and those which are closely tied to a burrow or a den. The behaviour of animals is thus seen to limit their freedom of action and as a result it orientates them in space; and combined with the physical barriers it indicates that these influences are important controlling factors in their successional relations. Many kinds of invertebrates exhibit similar local limitations. These influences determine the choice or selection of a habitat

(7) R. N. Ridley: *The Dispersal of Plants throughout the World.*

when an animal has a chance to exercise a preference. The behaviour of animals, as limited by their physiology, emotions, instincts and intelligence, is thus seen to be of the greatest importance in orientating them and the role which they play in any given animal and plant community, or as well in understanding their successional relations.[8]

The mass migration of gregarious ungulates of steppe-like areas in Asia and Africa when the dry season compels them to "follow the grass", and of the caribous and reindeer in North America in autumn and spring, is a successful response to the periodicity of climatic and ecologic conditions. This cannot be said, however, of the impressive blind march of the Scandinavian lemmings when they have exhausted the food supply of a district, for such migration leads to wholesale destruction. Various animals move from their birth-place to another more appropriate environment, while others regularly migrate to more suitable areas for the purpose of nesting and breeding. Thus migrations of birds, fishes and many animals are changes of habitat, periodically recurring and alternating in direction, which tend to secure optimum conditions at all times. These are purposive in the sense that this change of scene is associated with some definite advantage to the animal, and are periodic in the sense that they are the outcome of some recurrent change in the environmental conditions or in the animal's reaction thereto.[9]

MIGRATION AND HUMAN EVOLUTION.—During the vast climatic and ecologic changes which have taken place on the earth since the beginning of life, a vast amount of migration of plants and animals took place and man himself migrated to more suitable areas due to a change of climate or a shuffling of the flora and the fauna. Especially was this true for the greater part of man's history when he was merely a collector of food or a hunter. It was the stretches of open land or barriers of migration which determined

(8) General Ecology and Human Ecology, *Ecology*, July, 1935.

(9) A. L. Thompson: *Problems of Bird Migration.*

the origin and distribution of various species of plants and animals and the racial characteristics of the various types of mankind. Modern research has made it easier for us to reconstruct the movement of ice-caps, vegetation zones and of man himself in the ice-ages. Griffith Taylor is one of the pioneer workers in racial ecology who has interpreted the evolution and classification of the races of man by means of the "Zones and Strata" concept as applied to the mammals by Mathew, and has described the mechanisms of primitive migrations. "The region of stimulus" had been in Central Asia near the Caspian Sea while the "corridors of migration" were represented by the Danubian and the Chinese plains.[10] With changing climatic conditions the vegetation zones and characteristic fauna—and necessarily primitive man—moved South and North alternately. The great deserts, selvas and plains also varied very largely, stimulating or blocking migration. The "corridors of migration" also varied in character, sometimes being easier, sometimes being blocked by the vagaries of the changing environment. Through the ages two very definite motives for centrifugal movement from Asia thus existed: the advance of inclement climate, and of hostile and superior races. On the other hand, there was no similar "drive" back to the cradle land. There were necessarily only weaker earlier tribes on the marginal side. The climate in the margins would very slowly get hotter and less stimulating but this would merely slow up evolution. Indeed, that is why the Negro, who has lived possibly 100,000 years in the tropics has progressed so little beyond Neanderthal Man as contrasted with Alpine and Nordic types. However stimulating the tropical regions may be to lowly organisms, man does not experience in the tropics those daily integrations of energy which in the long run produce evolution. The laws of migration hold throughout the animal kingdom, the weakest are pushed to the wall, the strongest hold the centre and the "corridors of migration".[10] The capacity of mass movement and

(10) Taylors, *Environment and Race*, and also his article—The Ecological Basis of Anthropology, *Ecology*, July, 1934.

settlement in appropriate ecological areas of various animals is utilised for human purposes by animal breeders. Economic plants and animals particularly adapted to particular purposes and regions are being successfully introduced into similar ecologic areas. This applies also in some measure to the introduction of new varieties of insects and bacteria and the successful colonisation of the human group in a similar climatic region when faced with a limited food supply in the homeland. The wholesale migration and successful settlement of animals and human groups in similar climatic regions may thus be compared with the successful migration of many plants with creeping steps which are rapid colonisers of fresh ground. Conversely, the importation of very dissimilar strains, whether of plants or of animals and humans, leads to instability and degeneration.

ECONOMIC AND SOCIAL TYPES IN RELATION TO THE STAGE OF ECOLOGIC SUCCESSION.—Crops, agricultural and irrigation practices, methods of field distribution and village settlement invade similar ecological areas; and a population group with more adaptive farming methods becomes more successful in areas inhabited by others with an inferior culture and standard of living. Succession thus involves a complete change in the form of exploitation and in the type of population group. Through the interplay of the forces of competition, invasion and succession there is a natural selection of varieties of crops and domesticated stocks, methods of cultivation, types of human settlement, dietaries and standards of living in particular ecological areas. These are active agents in the selection and distribution of population types. The variety of food plants and of animals and the manifold uses to which these may be put by man's growing intelligence and experience govern materially the economic method and the social life of the communities concerned. The cumulative effects of climate, food and type of labour evolve the population type which can best utilise the resources of the region. The food and the standard of living are adapted to climate and ecological resources.

There is established a socio-physiological balance between man's normal output and expenditure of energy and the natural store of energy he draws upon. Again, in the same region there is always a certain natural dependence upon one another of different economic types that may co-exist, forestry, pastural industry, agriculture, manufacture and trade. We are here introduced to the idea of social symbiosis. There is a certain amount of hostility among the various parts within the life-community of a region, but a process of selection goes on till approximate reciprocal adjustment is attained, and the parts live in symbiosis.[11] The plants and animals of a life-community are similarly differentiated in time and space, and there are greater specialisation and variety as we rise in the scale of evolution. In the region some members of the ecological organisation provide the raw materials while others feed upon the surplus left over by the dominants or get their chance during parts of the year when the dominants are inactive. Then when the raw material has been lifted to the organic level, a new series of forms, the parasitic plants and animals play their part.[12] As in the human economic organisation, there are the major groups of primary producers (agriculturists, pastoralists, manufacturers, miners, etc.), intermediaries and consumers, so in the ecological community there is a similar chain of animal associations, each playing a well-defined role in the exploitation of resources. The plan of vegetable, animal and human communities tends to repeat itself even in many details of its arrangement. All these are embraced within the unity of life, with mutually adapted and interdependent parts, so that the balance and rhythm of the region are undisturbed.

THE ECOLOGICAL COMMUNITY A MOVING ASSEMBLAGE.—The main course of plant and animal succession is similar in similar natural habitats. Generally speaking, one stage of plant and animal associations gives way to the next, until an equilibrium is reached which is called a climax of the region. We do not find Nature working

(11) Mukerjee: *Regional Sociology*, p. 32.
(12) Wells, Huxley and Wells: *The Science of Life*, pp. 583-584.

in separate plant or in separate animal associations. Clements used in this connection the concept of the *biome* or biotic community constituted by plants and animals. Similarly, Shelford has emphasised the unity of the plant-animal community. According to him, because the large and more influential animals (mammals and birds) tend to range throughout units of largest (formational) size, the *biome* or biotic formation is the natural ecological unit, with some properties which are well illustrated by comparison with an organism. This he illustrates as follows: "The often mentioned effect of the bison on grass land is a matter in point, for if the bison held some of the mixed prairie in a short grass stage, then short grass is the bio-ecological climax, and its proper bio-sociological designation is *Stipabison*". John Phillips, who has recently examined the views of ecologists regarding the relations of plants and animals in natural communities, concludes that the most logical working concept is that of the biotic community. He suggests that as our knowledge increases we shall find that despite the linkage in certain instances of animals to plants which are relics of an earlier stage, despite the wide-ranging predilections of certain forms, there are definitely forms that are peculiar to stage, and that the ranging forms probably play a part in some special seasonal or other aspect of certain stages.[13] Man with his agricultural and industrial interference with the plant and animal associations, his modification of land-forms and natural sources of water-supply, etc., is yet a part of the biotic community. The region is in fact like an organism, plastic, growing, moving with its interdependent parts the associations of vegetable animal and human communities. The biotic assemblage, including man, acts as a whole, bringing to bear upon the environment only the surplus of forces remaining after all conflicts interior to itself have been adjusted.[14] It is usual to regard plant associations as absolutely inert and rigid. This is not a true picture. In the biotic assemblage every part strives

(13) John Phillips, The Biotic Community, *Journal of Ecology*, February, 1631.
(14) *See* C. A. Forbes quoted in (13).

for growth and dominance. Studies in plant ecology in reference to sustenance, environment, reproduction and linkage with other organisms suggest the general idea that plants are moving towards some betterment—towards more food, more light, towards multiplication and mastery. As Thomson and Geddes observe: "The concept of purposive endeavour, which is suggested by a study of the higher animals and is consciously verified in man, does not grip in the plant world, but that is not to say that it is irrelevant. We must think of the plant as if it were continually sending out tendrils which feel for support and often find it. Whence it begins afresh. This is the ecological picture."[15] The biotic community, including plant, animal and human associations, is thus a moving, reverberating system. Every part of the biotic community, as it seeks dominance, contributes to bring about a new balance in which the numbers and claims of all are well adjusted. Thus the biotic community as a system keeps on and even moves towards betterment through fresh individual endeavour and fresh inter-relation.

PIONEERS AND DOMINANTS IN PLANT, ANIMAL, AND HUMAN COMMUNITIES.—The physiographic factors, etc., determine the climax type of vegetation through successive stages, and each stage is associated with an animal assemblage through the provision of protection, shelter, breeding sites and food. But the climax types of vegetation take time to be established in a region. At first the pioneer species of plants, which are more plastic, such as algae, lichens and mosses occupy the soil. In community migrations, animals precede plants in many cases, that being due to more rapid migration. Animals are thus better short-period indicators than plants, observes Shelford. "Their presence and abundance at any hour, day, region, or cycle is indicative of conditions relative to which plants cannot fluctuate at all or must lag behind indefinitely. One thus sees the pushing of the dry-community animals into the wet-community in dry seasons, and *vice versa* as a regular phenomenon with attendant effects upon the habitat."

(15) *Life: Outlines of General Biology*, p. 199.

In much the same manner the pioneers or leaders among human communities first make their appearance in adverse environments, and are found like the pioneer species among plants widely and largely distributed under the most trying conditions all over the globe. Pioneer men like pioneer plants readily and quickly conquer new habitats. In a stable plant community the pioneers become scarce, and are killed out by the more complex forms of vegetation which can only establish themselves on soil prepared for them by the former. This also happens in human communities. The pioneer men and novel institutions prepare the ground for the stability and complexity of modern culture which ultimately weed them out. An ancient rural settlement is like a stable forest community, where the climax types among men completely overshadow pioneer types.

Important resemblances are also discernible between the modes of expansion of animal and those of human population. The recent investigations of Harrison and Hollom in Great Britain clearly show certain stages of migration and settlement of grebes which closely correspond with those of tribal invasion and settlement.[16] First, avian expansion, like all animal and human expansions, is by no means even but is subject to the conditions of drought, food supply and economic pressure. Secondly, there are to be found concentric zones of dense, medium, meagre and not yet attempted colonisation. At the original centre of population dispersion, over-population quickly follows, resulting in a bitter territorial struggle through the agency of which surplus pairs of birds are driven off and compelled to look for new sites. The favourable haunts are always over-stocked and the less rich among them are exhausted and finally abandoned. There is a gradual extension of settlement to less and less suitable sites, the birds attempting marginal sites under no settled system of territory, and probably not replacing their full numbers. An increase of population pressure

(16) *British Birds*, Vol. XXVI, 1932.

in the centre of dispersal thus leads to colonisation in less and less favourable sites and an increase of the landless class of birds, which are forced to settle down as non-breeding stock. The grebe is a newcomer in England and its distribution shows a marked contract to that of the heron, which is an ancient colonist and which has had time to develop strength wherever local conditions are favourable. In the case of the heron there has been a stable adjustment of numbers to territory and resources. The grebe, on the other hand, is a species dwindling, then suddenly expanding and colonising fresh haunts on an enormous scale, and, finally, passing from increase to numerical decline without ceasing to invade one fresh territory after another. Thus the dispersal of the heron and of the grebe represents a contrast in type which is discernible also in the case of many other animal movements. The fluctuations in numbers and migrations of the gregarious mammals have not been closely surveyed. But it appears that all mammals, which live according to a rigid territorial system, and migrate in herds or colonies, show features of colonisation and settlement resembling those of migratory birds. These are, moreover, observes Nicholson, closely analogous to recorded expansions of human populations; for example, the Norman overflow from Scandinavia to Northern France, and thence to England, Ireland, Sicily and Syria, which took a similar course, in a series of decreasingly successful invasions.[17] Birds and animals which do not rapidly fluctuate in numbers nor attempt constant invasions are in the occupation of haunts where the ecologic conditions, including the relations of the species to other animals, are relatively stable; and it is quite clear that the distribution of certain plants definitely restricts both the range as well as the mode of distribution of animal populations. For any gregarious species the density of population is determined both by physical and psychological factors which in the case of animals differ markedly at different seasons. Socially, any species has four limits on population density

(17) An Epic Bird Invasion, *Discovery*, October, 1932.

(1) limit of numbers which can rear broods on a given feeding area, (2) limit of numbers for foraging in company, (3) limit of numbers within a range in which daily assembly is feasible, (4) limit of occasional assembly (*e.g.*, on migration). In the breeding season (1) while little is known about (2) except that it is liable to be very much smaller than (3) in any given case.[18]

For its permanence the human community must also depend in its early stages on some special skill in the cultivation of certain plants and the rearing of certain domesticated animals. The distribution of different crops such as rice, wheat, Indian corn or vine, and different domestic animals selected from among the native stock of a region, may definitely limit the expansion of a particular race. On the other hand, such crops and animals govern materially man's interest and habits as well as his spatial relation to the region and the possibilities of organisation and labour. A definite type of labour imposed by climate and the assemblage of cultivated plants and domesticated animals favours the selection of a particular racial type suited to the region. But man's adaptation takes also the form of mental and social accommodation. Thus a type of culture comes to have a certain correlation with the physique of a people, both registering the trials and errors of the environment.[19]

THE ECOLOGIC AND THE CULTURAL PATTERN.—Lastly, as the ecological area passes through regular stages of succession, which are well-nigh uniform and predictable, with corresponding stages of development of plant and animal communities, both population type and distribution undergo a change with the transformation of the ecological base. The ecological area with its characteristic distribution of natural forces and harmonic animal and vegetable aggregations accordingly presents a well-defined patterned formation. As in the life-community in a region there develop a complex inter-relation-

(18) E. M. Nicholson has studied carefully the roosting habits of birds.

(19) Mukerjee: *Regional Sociology*, p. 230.

ship among the various organisms and a balance and rhythm of growth for all, so, in the culture of a human community which is woven within the framework of the ecological area, there is found a great complexity of interrelations among the social, economic and other institutions and traditions, establishing some kind of equilibrium for the whole community or culture. Thus, like the ecological community, society or culture develops as a whole, maintaining a balance for its different institutions and traditions, all interlaced with one another, as culture progresses, in finer and finer patterns of correlation and solidarity.

CHAPTER XV.

ECOLOGIC LAWS: BREAK AND REVERSION.

THE ECOLOGIC SAFEGUARDS OF NUMERICAL BALANCE. —The older the region, the more man-made it is. Yet old regions furnish the best illustrations of ecological laws and processes interwoven into man's works and experiences. Such stable and old areas of human settlement as spacious river-valleys can best exhibit not only a close ecologic adjustment of human spatial and food relations, but also the disastrous effect of the loss of a long-established ecologic balance on the human community. The Ganges Plain is the world's largest and most ancient area of human concentration. It is an ecological entity possessing what Vidal de la Blache calls an adapted and traditional genus of life. The nucleus of population distribution has here as its ecological basis the most accessible portion of the Ganges plain, *viz.*, the Ganges Jamna Doab. From here population has spread along lines of least resistance,—the banks of the main river and its tributaries. Along the banks of the lesser rivers and minor streams and towards the delta human settlement has been less recent, while at the same time the social composition exhibits a preponderance of the agricultural tribes and castes having a lower culture and standard of living. But throughout the ecological territory where population multiplies as rapidly as climate, soil and water-supply permit, the general mode of existence is represented by intensive agriculturists. Brunhes and Vallaux, speaking about the Indian and Chinese river plains, observes: "In the regions of water and sunlight, men increase and multiply themselves as plants increase under the influence of a fertile environment. The harvests of rice, millet

and dowrah, won at the price of moderate and routine labour, suffice in normal times to nourish the new mouths; the increase of population takes a pace almost as regular and mechanical as the seasonal return of the nourishing plants; when human increase moves more rapidly than the fruit of the seasons, the check operates and harmony is re-established by means of measurable forces and also by means of deeper forces which geography is not able to get at". Among these deeper forces are those of natality and mortality, which strike out a nicely adjusted balance of human numbers and food supply in the region. Thus, where man by his capacity of reproduction creates more mouths than what his intensive toil in the field can feed, nature re-establishes an ecological balance by adjustment of birth and death-rates. Man's mode and capacity of exploitation and his rate of multiplication exhibit some kind of mutual harmony in the ecological territory where he has lived, toiled and multiplied for generations. It appears that wherever he multiplies imprudently and his numbers vary too far from the optimum density which is locally desirable, Nature regularly and mechanically sets in motion certain biological safeguards correcting the numerical instability. It is thus that many dissimilar species and functions reciprocally adjust themselves to a common subsistence in the ecological territory. From the point of view of numbers, the region is at once an economic and biological unit, the whole of the ecological community being operated upon by natural selection so as to bring about the best compromise in the way of optimum populations for all.

THE REGION, A SPECIFIC PATTERN OF LIVING.—A sharply defined genus of life which may be regarded as an inter-connected whole has prevailed over the largest alluvial plain in the world, and attained a highly developed form re-presenting the connections and repurcussions between the human masses and factors of the environment for centuries. The reciprocal action between man and the region is here consolidated, emphasising and increasing the present specific character of the region.

We may briefly illustrate the scope of human ecology by the following orientating diagram.

REGION.

Man	Biotic factors:	Forms of exploitation
		Form of agricultural practice
	Type ..	Old alluvium
		New alluvium
	Intensive agriculturists ..	Flood plain
		Delta
		Crops
		Rotation
		Yield
		Security
		Irrigation practice
		Canals
		Wells
		Flood or flush irrigation
	Agricultural regions ..	Communication and transport
		Population
		Density
		Distribution
		Health
		Standard of living
River Valley ..		Village Settlement
		Dwelling House
		Rhythms of rainfall and the year's agricultural work. Cottage industries and factories
	Physical factors: ..	Climate, soil, river-form, etc.

Man and the wider environment, indeed, have evolved together through mutual influences. Land, water, tree and man are by no means separate and independent factors, for by reciprocal influence they form a natural equilibrium parts of which can be understood only in terms of the other. It is a self-limiting system in which the forces of action and interaction bring about an equilibrium which is constantly shifting. Such an understanding of regional inter-relations is not only a fruitful advance in the study of social causation, but at the same time it will also promote that alliance of man with the entire range of ecologic forces in which lies his real security and progress.

MAN'S BIOLOGICAL SYMBIOSIS OR PARASITISM.—How far does man, considered in his expression of

population density, live harmoniously (symbiotically) with the ecologic forces of the region? How far has he multiplied in numbers beyond the resources of the region that he occupies, thus setting narrowing limits for himself when nature is capricious? How far, again, has ignorance or reckless disregard of the proper balance and rhythm in nature brought about the poverty and ruin of future generations? These questions in human ecology have an enormous practical importance for millions of people living in the steppe and prairie areas of the Upper Plain, in the malaria-stricken deserted hamlets of the moribund delta, or in the flood-swept settlements of the active delta of the Ganges. Famine and flood are equally manifestations of man's crime against Nature and Nature's stern rebuke. Where formerly there were arid wastes man by his skilful engineering and patient effort introduces smiling fields. Where again, there were bountiful orchards and fertile fields, man by his unskilful interference with the natural drainage brings about agricultural deterioration and epidemics of fevers. Everywhere man has thriven in numbers. The encroachment on the mountains by the tilled land spells ruthless destruction of the forest covering. This has cumulative bad effects, tending to decrease the humidity of air, the equality of temperature and the fertility of the region. As the mountain slopes are laid bare, the erosive forces are further let loose for these, by destroying the soil cap on which forests have flourished, render forest growth impossible for some generations. The mountain torrents, formerly harnessed for irrigation, now become devastating floods, while the accumulated stores of mineral salts in the mountain soil are scattered upon the plains below, thus adding further to strips of barren waste. Man has also gone to the brink of swamps and reclaimed marshes for the plough. This, coupled with the continuous exhaustion of sub-soil water reservoirs by means of thousands of alluvial wells, lowers the water-level. As the water-level goes down pastures are depleted, and certain crops are no longer grown, while there is a great strain on bullock power especially in summer when fodder is scarce. As population and cultivation expand,

both human and cattle populations, encroach upon the jungle-belt on the banks of the rivers. With the destruction of vegetation on the river bank, the forces of soil erosion under the heavy monsoon rainfall have free play, and we have an enormous loss of fertile soil, which is carried into the rivers, and the extensive formation of desert-like and inhospitable ravines. In the lower reaches of the river, the increase of population leads to the construction of embankments, roads and railways, which facilitate the silting up of river beds and the change of watercourses, this being the legacy of decline in fertility, water-logging and fever prevalence. In the areas over which the rivers still exercise their delta-building functions, making and unmaking the landscape, man forms his settlements on the banks of the mighty rivers, whose waves now now and then destroy his fields and habitations. Near the estuary rivers more often than not get out of hand and ravage the country. Man has also polluted rivers by the discharge of sewage, and building of dams. It has been found that sewage in rivers exterminates certain species of fishes, drives most of them down stream, and makes the upper reaches of a river in a sense an aquatic desert.

CIVILISATION, A WHOLESALE BIOTIC INTERFERENCE.—But man's destruction of the wild animals and birds of the forests has been on a much wider and wholesale scale; and this has led to the deterioration of the faunal standard in many regions. It is well known that buffaloes, which once grazed in countless herds over the prairies of North America, can never do so again and that their place has been taken by herds of beef cattle. Many tracts of Northern India over which the vegetation has been reduced to scrub and thorny growth are practically devoid of the larger mammals and birds except those which man favours or tolerates while there has been a multiplication of small mammals such as squirrels, rabbits and rats.

Forbes and Gross have pointed out that birds are not changed to any extent by man's modification of their environment but seek out the habitats that most nearly resemble those they occupied before. Prairie birds come to

live in pasture; thickets birds turn to orchards. As the human settlement pushes into the frontiers of the steppe and the jungle, birds became scarcer and scarcer, setting free various injurious insects to destroy man's crops and permanent products. Man may destroy or diminish his food resources through his artificial introduction of influences that make the habitat unfavourable for particular animals, by depletion through the removal or destruction of too large a number of animals in a particular area and by other acts. It appears that throughout the world man, on account of his lack of knowledge and foresight, is slowly but surely depleting aquatic food-resources by over-fishing. But wherever man has acquired an adequate knowledge of the life histories of pests and parasites he has increased agricultural productivity, fought cattle epidemics and rid the country of malaria, yellow fever or filaria. The use of minnows has been successful in freeing Guayaquil from yellow fever at little cost.

Man has successfully raised domestic animals suited to local climatic conditions, or by means of crossing, introduced new animals, or improved their milk flow, flesh or reproductive capacity by careful mating. In general, domestication implies the transformation of an unfavourable into a favourable environment for animals, though it is also accompanied by new risks of degeneration and disease. On the other hand, man has unwittingly introduced new animals into areas where they have done great havoc. Familiar instances are the introduction of the rabbit into Australia, the mongoose into Hayti and the English sparrow into the United States. A European carelessly introduced a weed into a stream in Canada and into a pond in Eastern Bengal and both the Canadian water weed and the Bengal water hyacinth have choked the rivers and watercourses. In Canada the weed, however, ceased to spread and a balance was established and the weed has now settled down to become a normal and innocuous member of the flora. But in Eastern Bengal the water hyacinth still spreads and has become a serious obstacle to both

transport and agriculture. Some animals have become pests because they are protected by man. When fishing is restricted by law to sportsmen's methods, undesirable species multiply beyond their normal numbers. Geese and ducks are protected in Alaska where they do much damage by destroying herring eggs. Pearse concludes his study of the economic relations of ecology thus: "As the earth becomes more thickly populated, it becomes more and more necessary to keep natural habitats from being ruined by carelessness or by the bye-products of man's activities. Laws to prevent the introduction of plant and animals that may become pests and laws that prohibit contamination of habitats by wastes are increasingly necessary".[1] It is by co-operation with the ecological processes that man is enabled to deal successfully with animals and insects of the habitat when these cause his suffering and death or injure his animals and crops. Thus in dealing with the serious plagues of mice, rats and other rodents which occur from time to time in various parts of the world, money need not be spent in fruitless killing. Such destruction merely postpones the date of outbreak of the normal epidemics which bring their numbers to an optimum density, and thus may maintain the plague for a longer period than would otherwise have been the case. Thus as Julian S. Huxley observes, "If remedial measures are to be desired, they must be of some special sort. Either they must encourage the development of the epidemic, as by introducing infection among the wild population of the pest species; or they must aim at reducing reproduction, as in the Rodier anti-rat compaign, where after trapping only females are killed and all males liberated once more; or they must be aimed at the general ecological status of the species, making it more difficult for it to live and reproduce, as has in another sphere been accomplished by drainage and cultivation with regard to the malarial mosquito."[2] Malaria, yellow fever, dengue and filariasis have all been fought and overcome by altering the environmental conditions of the mosquitoes in such

(1) *Animal Ecology*, Chap. XII.
(2) J. S. Huxley's Introduction to Elton; *Animal Ecology*, pp. xv and xvi.

manner that these may not live and thrive and transmit these diseases. Similarly, hook-worm infestation has been checked by the prevention of soil pollution. Man has also sought the alliance of animals and insects in fighting with pests, both animals and insects. Pests are commonly attacked by him during those periods in their life-histories when they are merely vulnerable or easily accessible. Thus rats are hunted with ferrets; foxes are pursued with dogs. Against insects, parasites and predaceous enemies are commonly employed. Such allies of man as ichneumons, evanids, chalcids, tachinids and fungi are reared and scattered about in localities where they will be of most value. Where agriculture is endangered by an insect pest, its direct eradication may often be found impracticable in a particular habitat. Thus it is more practicable to adopt improved methods of cultivation or to breed resistant strains of the crop plant.[8] In all this we realise that wherever man has understood the complex web of life, he has lived more harmoniously with the region, especially in a climate where his cold-blooded rivals, the plant pests and, most of all, the insects have an initial advantage over him.

Man in order to control Nature must to a large extent follow her, for Nature has her own wisdom. If he seriously disturbs the balance and rhythm in which Nature delights vengeance often follows quickly and man has no escape. Man cannot with impunity upset the balance of Nature any more than he can prevent the operation of the laws of motion and energy. Such balance may or may not be to his advantage; and when man changes it he should assure himself that the new balance is to his advantage. The ecologist forecasts successions and developments marking Nature's shifting balance. Human ecology is also intimately concerned with the future of human successions. It is the task of applied human ecology to trace man's deterioration when by his own activities of exploitation and reproduction he upsets the balance of the region. Plant and animal as well as

(8) For ecological central problems see, A. D. Imms: *Recent Advances in Entomology*, Chapters XIV and XV.

human communities exhibit changes which seem to take place in cyclic recurrence. With the physiographic and hydrographic decline of the region, due both to natural causes as well as to "biotic" interferences, there is a deterioration of the standard of flora and fauna, and man also returns through epidemic or famine or both to a lower, uncrowded pastoral existence even in ancient and fertile valleys. Civilisations thus come of age in ancient areas of settlement. Applied human ecology envisages the pictures of man's manifold development as his activities are in harmony with ecologic balance of population and resources as well as of vegetation and animal life, being more of the nature of a biological partnership than a one-sided mensalism. A city, a market or a machine once destroyed may be rebuilt, but a region which has lost its fertility, moisture and vegetation cannot be renewed, and this seals the doom of historic cultures. Thus the dictum, "after man—the desert or the jungle", epitomises the recurring tragedy of civilisations, which have gone in the same way of cyclical regression as plant and animal communities.

THE ROLE OF PARASITISM IN ESTABLISHING NUMERICAL BALANCE.—The food inter-relations of animals in the ecological territory may come under either symbiosis or parasitism. The relations of symbiosis or parasitism are flexible; those which hold good in one region do not hold good in another, while there is no definite boundary between symbiosis and parasitism, both representing phases of gradual and reciprocal adaptation of associated organisms in the same habitat. In perfect symbiosis the associated organisms are completely adapted to a life and subsistence in common. In parasitism the degree of adaptation varies greatly; it may approach symbiotic conditions, on the one hand, or range to vanishing point in the other by leading to the death of the organism that is invaded by a highly pathogenic animal or vegetable disease agent. Apart from the series of food-chains, which link the activities of organisms in an ecological territory, parasitism thus is one of Nature's familiar

methods in reducing an undesirable density for a particular species of animals. Symbiosis itself is supposed by some to have originated through a preliminary stage of parasitism on the part of one or other of the associated organisms, the conflict between them in the course of time ending in mutual adaptation.[4]

In the ecological organisation of life-community symbiosis and parasitism represent contrasted threads of inter-relations. In fact the modification of habits, functions and physiological requirement of both symbionts and parasites, and the role they play in establishing a numerical balance of plant, animal and human communities in a region, is exceedingly important. While the natural enemies bring down the numbers of a species of animals to an equilibrium density, disease also occurs when a parasite lives at the expense of its associated organism in whose body it has established itself and disturbs its metabolism. In wild nature animal numbers are, however, controlled normally by natural enemies rather than by disease, the inter-relations of organisms in the same region showing a working compromise of mutual bio-economic advantage and average abundance for all. Biologists now emphasise the importance of biological control in the re-establishment of population balance. General limiting factors such as climate, it is urged, act in proportion to the numbers of the organism they affect, whereas individual limiting factors such as parasites, destroy an absolute number, because, for example, an individual parasite can only lay a certain number of eggs irrespective of whether the heat is abundant or scarce. Some entomologists, however, adduce examples to show that these individual factors may increase even more than proportionally. A true regulating factor would be not a proportionally increasing one, but one that would grow more than proportionally during a climax (increase in the reproductive rate) and again fall more than proportionally during the decrease in the num-

(4) G. H. F. Nuttall's address, *British Association for the Advancement of Science*, 1923.

bers of an organism (anti-climax of the reproductive rate). These factors affecting the population equilibrium of insects have been recently studied authoritatively by Martini.

The success or failure of a species of plants or animals in a given region is measured by the growth of or decline in its numbers, and their fitness to the environment or prevalence of disease. In each ecological territory a bio-economic balance, although a shifting one, is established between the different species of plants and animals, which are co-acting numbers of an integral life-community. There is an ecologic adjustment of the rates of multiplication of each species of animals in the life-community as well as of their natural enemies and parasites. There is rarely a complete destruction of the parasite or the appearance of an epidemic in the host, all animals including the parasites multiplying to a state of an average abundance. Epidemics occur only when animals, on account of abnormally favourable conditions of climate and food supply, outrun the check of their normal enemies and pass through "Storms of breeding".

Man in his efforts to secure favourable and stable conditions of food supply is both herbivorous and carnivorous, and is the most subtle and domineering of all parasites. His ways of exploitation of the entire regional complex are as devious as they are relentless and far-reaching. But as he turns up and exploits the soil, uses or wastes water, destroys vegetation and preys upon the weaker animals, the vegetable disease agents and pathogenic bacteria may sweep off human numbers *en masse*. Both among animals and men, parasitic infections are symptomatic of the organism's inadequate adaptation either as an individual or as a species in the biotic community. In wild nature as normal enemies multiply, or change their preference according to the scarcity or abundance of their victims, or as disease spreads from one species of animals to another and is hereditarily transmitted from host to host, an optimum population for all in an ecological territory is reached.

Man, however, through artificial conditions of food supply, shelter and comfort has constantly interfered with Nature by preventing the drastic operation of natural selection, which weeds out diseased individuals among plants and animals. He has also obtained his own release from the natural biologic checks that restrict animal populations, while his sexual activity, unlike that of the majority of the animals, is not restricted by seasonal conditions. Thus he has rapidly multiplied, thereby enormously increasing the biological pressure under which he lives. Not only has this lowered his own living standard and vitality, and set a limit to the possible variations of mind and body, but it has also brought about unforeseen disturbances in the life of inorganic and organic Nature. It is these which account for the prominence of disease and low health standards of man as contrasted with the absence of disease in wild nature. Man's illness or disease is in fact one of the penalties of his disturbance of the organic and numerical balance found in nature.

EPIDEMIC AS A SYMPTOM OF THE BROKEN ECOLOGIC CYCLE.—That the spread and virulence of diseases, which are all important factors in reducing animal and human populations to a locally desirable equilibrium, illustrate a disturbance of long-established linkages is now coming to be recognised. Modern researches in epidemiology and bacteriology indicate that the spread of many epidemic diseases is incidental in the life-history of pathogenic organisms whose lives touch plants, vegetables and humans in an unbroken cycle. In over-stocked grass lands inhabited by grouse, in prairies densely crowded by small rodents or in packed human settlements, epidemics break out and sweep away large numbers of birds, animals or humans. Conversely, such epidemics die out if the density of their victims is too low. Man's deterioration of vitality, usually due to increase of population pressure, gives an opportunity to various pathogenic bacteria which are introduced into his body by plant-bugs, fleas, gnats, lice, bed-bugs and other insignificant creatures.

Already plants and animals may, under normal or diseased and abnormal conditions, harbour the pathogenic parasites whose effects upon man often represent an instance of the broken balance of nature in which every part of the living world is implicated. The transfer of the parasites from plants and animals to the human hosts is thus symptomatic of a serious disturbance of the rhythm and balance of the entire life-community of the region, and such transfer often shows some of Nature's subtlest linkages and adaptations. Man himself plays an ignoble part in importing diseases into plants and animals, for it is usually in artificial, humanly contrived conditions that diseases appear in wild nature. Due to man's infection of the earth and water or to his importation of new plants or animals into a region, or disturbance of the long-established food-chains among animals, diseases appear in Nature and then the evil recoils upon man himself in forms of devastating epidemics. In the case of such diseases as sleeping sickness and bubonic plague, it is clear that the virulence of the epidemic depends upon the introduction of either parasites or humans into new areas, a case of imperfect adaptation. It is well known that certain insect-borne diseases seem to be associated with certain climatico-botanical regions, and their native stock of animals and humans establishes an immunity to them after a long adjustment.

RECIPROCAL BALANCE BETWEEN PARASITE AND HOST.—No doubt the common species of human parasites are far older than the human race itself. The adaptation of the parasite to certain particular species of hosts, whether animals or humans, has gradually developed over a long period of years and in this reciprocal adaptation climatic and edaphic factors, as well as the general distribution and the food and drink habits of particular species of hosts, are important factors. E. C. Faust, discussing parasitism in the animal kingdom, concludes that at the dawn of history, *foyers* of helminthic bacterial or protozoal infection were distributed throughout the entire habitable world. In the first place, many

of the animal parasites of man are also common infections of other mammals; in many instances man is only incidentally infected. In the second place, certain infections which are apparently non-pathogenic for other animals cause severe symptoms in man, thus giving evidence of a shorter period of adaptation in the human species. Furthermore, many of the parasitic forms which now require two or more hosts, including man, in which to complete their life cycles, may have originally only utilised one, the present larval host. Finally, physiological differences among parasitic species in men and mammals, where morphological structures appear to be identical, indicate that the parasite has become established in the human kind sufficiently long to have acquired a relatively fixed adaptation.[5]

Many races have shown themselves more adapted to helminth parasites than those in which the infection is relatively new. The Negro is, for instance, less seriously affected by hook-worm infection owing to the presence of Ascaris in the bowel than is the Caucasian, and a single infection of Schistosomiasis assumes a mild chronic form in the native population of endemic areas more commonly than in the foreigner.[6] The acquired immunity of indigenous peoples to the malarial parasites of their own locality is also well known. The Terai in Northern India is a dangerous area to all newcomers, yet the aboriginal inhabitants like the Tharus and Bhoksas are not killed off. It appears from recent laboratory experiments that this acquired immunity is an immunity only for the particular parasites of the locality. This explains why a body of men possessing apparently a relative immunity to malaria in their own area may suffer severely when moved to another distant place. For instance, coolie labour from South India if moved to Malaya may readily become infected with a different Malayan parasite to which they have no immunity and in return may infect the Malayas with the South Indian parasites they have brought with them. The

(5) Faust: *Human Helminthology*, p. 34.

(6) *Ibid.*, p. 30.

danger of mixing the breeds of malarial parasites is probably illustrated by the virulent and epidemic malaria from which the British army suffered so much at Salonica where there were collected troops from various malarious centres such as the East Indies, the West Indies, French Colonies, Italy, Greece and Serbia.[7] In a broad biological sense, the parasite becomes associated with certain particular species of hosts, and the process of adaptation has gone on over a hundred thousand years. Where the parasite has reached an equilibrium with a host, there are no clinical symptoms of a disease. "Between the perfectly adapted parasites on the one hand and the entirely non-adapted ones on the other there is a wide range of ill-adapted species, whose relations to the host produce a reaction of the tissues, which the pathologist and clinician look upon as disease." In the case of many protozoal infections, such as malaria, trypanosomiasis and amoebiasis, a similar balance between the host and the parasites has been reached so that the former is injured to a minimal extent, while the parasite can reproduce sufficiently to maintain itself. On the other hand, whenever we see that the balance is broken down and the disease becomes virulent and carries off large numbers in an epidemic form, we may safely assume that the race of parasites is different, or that the host is not the natural one, or that it is a natural one which is in some unnatural condition. After a time adaptation may occur, and a host which was at first an unnatural one may gradually become a natural host. In the case of the pathogenic trypanosomes of Africa, the natural hosts are the antelopes, to which they do comparatively little harm, while human beings and domestic animals are unnatural hosts as they are much more seriously affected. Man seems already to have become a natural host to *Trypanosoma Gambiense,* but to be only in process of becoming so for T. Brucei (T. *Rhodesiense*).[8]

In equatorial Africa with its luxurious grass and herbaceous growth of many years old where antelopes,

(7) Note on the Research Work in Malaria, *Indian Research Fund Association*, 1934.

(8) C. M. Wenyon: *Proto-Zoology*, p. 135. Similarly the Indian aboriginal peoples are less seriously,—if at all—affected by black-water fever than the civilised Hindus who live in cities—a similar case of imperfect adaptation.

buffaloes and many other wild animals abound, these serve as an ample reservoir for supplies of trypanosomes for domesticated animals and for humans who die by thousands. Outside the fly region, however, the wild animals do not exhibit trypanosomes in their blood and in fact the distribution of the disease coincides with the distribution of the tsetse fly. The "primary centres" for the tsetse are associated with ground water during the dry season, luxuriant vegetation and the presence of abundance of game. Thus the clearings of vegetation around lake-shores and along watercourses have as their object the alteration of the conditions favourable to the fly. Clearing and controlled fierce firing have, indeed, been found an excellent weapon in the destruction of breeding-place thickets and pupae. Regarding the introduction of an exotic predator or parasite, J. F. V. Phillips remarks that an indigenous predator or parasite can hardly keep in very marked control an indigenous pest. "We possibly are wasting energy searching in tsetse-infested Africa for a virulent biotic controller. We should look, perhaps more logically, either in portions of the continent uninfested by the fly or better still in South America, Asia or Australia."[9]

Duke's researches tend to show that if the trypanosome remains too long in one animal its power to establish itself again in the fly is lost and it becomes non-transmissible. On the other hand, when passed quickly by mechanical means from one animal to another the trypanosome is invigorated and extends the area of its distribution. But at the same time its rapid multiplication within the animal results in disturbance of the normal balance, and disease ensues. To avoid epidemics it is thus important to prevent fly from rapidly transferring the trypanosome from one animal to another and thus the presence of fly and animals, or man, in numbers together must be avoided.[10]

EPIDEMICS IN RELATION TO THE CONCENTRATION OF CARRIER OR RESERVOIR.—The distribution of a protozoal disease like yellow fever or sleeping sickness is limited

(9) J. F. V. Phillips, The Tsetse Problem in Tanganyika, *Ecology*, October 1930.
(10) Carpenter: *Insects as Material for Study*, p. 10.

thus by three factors (i) the presence or absence of carriers such as the *Stegomyia* and the tsetse, (ii) the reservoir from which the infection spreads, and (iii) the predisposition of the new host whether animal or human. In the case of yellow fever the carrier is widely distributed in many parts of India, yet no definite case has yet been recorded of a true case of this fever, and stringent regulations are instituted to prevent importation of the virus of the disease in any form whatsoever for experimental purposes. In the case of sleeping sickness, on the other hand, neither the carrier nor the reservoir is found outside Central and South Africa. Consequently the disease is circumscribed within definite ecological areas. It has been found experimentally that the specific carrier, even when imported into other areas, cannot thrive, probably because of the unsuitable physical conditions, vegetation and food supply. In the case of plague the abundance of the carrier or the reservoir even in the epidemic area varies a great deal, causing fluctuations in the virulence of the disease. In India the mortality from plague now amounts to only 2 per cent. of the total plague deaths since the outbreak began. The Punjab and Bombay are the provinces which have suffered most heavily from plague. It is in these areas that the reservoir,—the rat population—, is more immune to the disease than elsewhere in India. This is no doubt due to the more susceptible of the rat race having already died of plague, leaving their more immune relations to survive. In the endemic disease area the disease disappears for a long time but crops up again virulently after a longer or shorter interval. Research work indicates that although there may be no disease amongst men, the plague survives in rats and their fleas, and also to a less extent amongst bandicoots and house mice. The carrier, the flea, it has been found, can, even when starved, spread the disease for as long a period as sixty-three days. In the endemic disease area, the rate of dissemination is thus directly dependent on the concentration of the parasitic content, the intermediate hosts, mammals and birds, as well as the density of human population (the definite host). It is highly probable that

malaria cannot be transmitted except through the agency of the mosquito. Where the disease is most severe, the *Anopheles* mosquitoes are present in enormous numbers. It is interesting to mention that the *Anopheles* mosquito, to prevent complete annihilation during the winter season when its numbers are much fewer, breeds a greater number of times than other mosquitoes during summer and the rains, and thus continues the generation of future carriers. The same fact can also be demonstrated by the quicker completion of its life-cycle during the approach of winter and very hot summer. Otherwise the long exposure for two or three weeks to extremes of temperature would prevent the life-cycle being completed. It is thus that the life-cycle of the intermediate host adapts itself to local and seasonal conditions and contributes indirectly to the transference of the parasite from the reservoir or the human hosts.

In the evolution of an infectious disease we accordingly find that the transition from the endemic to the epidemic form occurs readily where direct contagion is possible, or in the case of a disease common to man and other mammals spread by an insect vector by the adaptation of the virus to the insect parasite peculiar to man. Charles Nicolle, who has studied the evolution of infectious diseases, cites the relapsing fevers as an example of the latter phenomenon—the European variety spread by the body louse being the only one to assume epidemic proportions;another example would be typhus and the typhuslike diseases such as the scrub typhus of the MalayPeninsula and Rocky Mountain spotted fever. Possibily the malarial parasite can complete its cycle of development in other animals than man. Sparrows have been known to suffer from malaria transmitted to it by the *Culex* mosquito. A strain of natural malaria infection has been recently discovered in a *Circopithecus* monkey from Singapore, which causes malaria of a mild, chronic relapsing type in these monkeys. In monkeys of the genus *Macacus*, however, the infection is very severe, and resembles the most severe type of malaria in man. The infection is also transmissible to

human beings in man, the parasite causes true malaria but it does not become converted into one of the three species of malaria parasites responsible for malaria in man. Different species of monkeys show great variations in resistance or susceptibility to infection and in some the disease proves fatal and is often accompanied by black-water fever. The Singapore monkeys, especially the young ones, appear to be infected in nature almost without exception. On the other hand, Bengal monkeys seem to have no naturally acquired malaria at all, although they are extremely susceptible to infection. It, therefore, seems possible that when Man—*Homo sapiens*—came into being in the Mongolian, Indo-nesian and West African foci, the anthropoid apes of those regions were already infected with a species of malaria parasite, which could be transmitted to man by the local *Anopheles,* and that it was from some such source that human malaria, the most important disease in the tropics and sub-tropics, arose. It is also possible that originally the malarial organism was derived by the mosquitoes themselves from the stems or other parts of aquatic plants and that its effects on man are incidental phenomena due to the aggregation of men in dense masses in the damp and marshy areas where the mosquitoes breed.[11]

CHANGE FROM THE EPIDEMIC TO THE ENDEMIC FORM AND THE RESTORATION OF NUMERICAL BALANCE.—But though incidental the effects of parasitic or protozoan disease are to re-establish the balance of nature broken by the undue multiplication of any animal or human communities. Wild buffaloes, antelopes, deer, rabbits, hares, lemmings, rats, mice and other animals undergo in most parts of the world regular and violent fluctuations in which epidemics play an important part. As their numbers overstep an equilibrium density, disease disposes them off, and the epidemic has important effects both on the quality and the quantity of the population. Gradually as the numbers dwindle below an average, the infection ceases to spread or the herd immunity of animals and humans is so raised that the diseases become progressively milder, some finally

(11) Folsom: *Entomology,* p. 252.

disappearing, having passed through the phase of *infections inapparentes* in the process. The epidemic is followed, in the case of most animals including men, by increase of population due to natural recovery, and probably climatic influences as well as conditions of food supply speed up the rate of reproduction in certain years. Thus different kinds of living creatures which sojourn together throughout a region become adjusted to a viable balance, there being a rhythm of growth or multiplication for all so that the life-community keeps on and evolves as a whole. When man upsets this locally or temporarily, he cannot escape from the operation of those processes by which Nature seeks to restore her long-established correlations of numbers.

TASKS OF PRACTICAL ECOLOGY: REGIONAL PLANNING AND ORGANISATION OF THE HUMAN HABITAT.—We may now indicate the field of applied human ecology.

Man	Social Regression	Social Evolution
	Deforestation ..	Preservation and plantation of forests.
	Mountain denudation and field erosion.	Tree-cropping in the hill slopes.
	Single and conitnual cropping.	Scientific pasturage and permanent agricuture.
	Surface tillage, defective soil aeration and drainage.	Conservation of rain, river and sub-soil water-supply.
	Soil exhaustion ..	Plant and animal breeding and introduction of new strains.
	Deficiency diseases of animals and humans.	Selection and use of micro-organisms in cropping.
	Diminution of irrigation water-supply.	Ecological control or eradication of plant and animal pests.
	Alternate visitation of flood and drought.	Preservation of animals and birds from extinction.
	Desiccation ..	Conservation of the environment suitable for animal and human habitation.
	Destruction of crops and herds by insects and parasites.	Regional planning of villages, cities and industries.
	Destruction of too large a number of animals and birds for food or materials.	Economic balance between the forest, meadowland, field and factory.
	Contamination of the region by wastes and sewage.	
	Silting up of rivers and loss of natural drainage and flush irrigation.	
	Growth of jungle in human settlements and of weeds in streams.	
	Spread of bacterial and protozoal infections	
River Valley	Depopulation in the country side and congestion in the big cities and manufacturing regions.	

The stimulation and development of life-processes of a whole region depend upon the maintenance of a balance and rhythm of the different parts or levels of the region, from forest to tilled land, from high land pasturage to the water level. Social ecology sees the different sections of the region as belonging to a single whole and pleads for conservation both of natural resources and human values not merely in the denuded mountain slopes, in the impoverished fields and in the depopulated villages but also in the industrial cities and manufacturing regions.

Social ecology thus aims at establishing a state of economic balance of the whole region with its population fairly and adequately distributed with reference to the economic potentialities of each section of the region. Thus the forests and forest products, minerals and grass land resources, agricultural land and water supply as well as the varied skill and aptitudes of the people will be adequately utilised and the region will develop a variegated type of economic life in each section as a basis for its own social pattern. Forestry, the extractive industries, animal husbandry, agriculture, manufacture and trade will be co-ordinated. Each will contribute to the development of the allied or subsidiary economic type in order that the population as a whole may be richer and at the same time live more in harmony with the earth and its forces and with the legacies of vital traditions that past generations have intermixed with the region. On the mountains the preservation and plantation of forests are indispensable for stabilising the mountain stream flow, preventing erosion of the hill slopes and probably also for increasing humidity of the air and local rainfall. All these react favourably upon man's economic and living standards. On the mountain slopes the tree-crop type of agriculture saves the hill sides from destruction and thus benefits the agriculture of the plains. In the meadows, scientific or rotational grazing with regard to the interest of the future, or an arranged succession of leguminous fodder crops with cereals, is the chief support of intensive farming. Thus the different levels or sections of the valley will develop each

its appropriate type of permanent agriculture in relation to the region forestry on the mountains, tree-cropping in the slopes and rocky places, forage-cropping in the meadows and grass lands and intensive cereal growing in the level plains. It is in this manner that man can best utilise the resources of the plant kingdom for his permanent well being; on the other hand, if he brings the agriculture of the level valley into the mountains, denudes the mountain sides and cuts down forests and continually encroaches upon grass lands, the regional solidarity is disturbed and man will have to repent for his folly and want of foresight. Schemes of afforestation in the mountains, the cultivation of nuts, dates, oranges, olives, apricots, figs and other tree-crops in the hill slopes, conservative pasture management in the grass lands and permanent agriculture and irrigation in the level plains—all are equally necessary in order that man may secure a stable basis for his life and civilisation. Furthermore, as agriculture and rural life are stabilised, the whole region becomes re-invigorated and rehabilitated and culture and civilisation are no longer confined to a few industry centres and "connurbations" but are established at every point in the region where the economic basis for a community life can be found. Such a harmonious regional development will eliminate the enormous waste of soil and water, bring about a balance in the region's economy between the field and the factory, between the village and the city, give a new life to agriculture and restore to the human community some of the permanent social values which have been sacrificed in man's one-sided exploitation of nature, and his unbiologically rapid use and lavish expenditure of Nature's stores.

DISCONTINUITY AND REGRESSION IN THE URBAN ENVIRONMENT.—Man expresses the lag in his adjustment to the artificiality of the urban environment by lower life expectation and greater mortality than in the rural areas, due to causes which are preventable and largly man-made. Differences of atmosphere, food and water-supply, clothing, lighting and personal contacts, as well as the conditions of work in closed spaces, have all contributed to stunt the opportunities of both survival and development for urban

dwellers. Indeed, the cityward drift throughout the world has made it indispensable that medical and social science should inspire the city architect and municipal engineer in quelling the disorder and confusion of the last five decades of unplanned urban and industrial expansion. Thus modern civic and industrial conscience has set before itself the tasks of decreasing the health hazards and providing the physical conditions of clean and moral living in the larger human aggregations. Yet man, in spite of his success in securing wholesome atmosphere, unpolluted food and water, open space, ever green vegetation and even privacy of life in the city, and his nervous adjustment to the floating throng in the street, factory and office, will still require the bracing and re-invigorating contact with the elements in order to maintain his aesthetic and intellectual delights. His effort in the future will accordingly be concentrated less towards securing the conditions of safety and survival in an artificial environment by device than towards a re-distribution of people and occupations in the different sections of the region, which will restore to man the intimate touch with the invigorating realities of outdoor life. The part which the emotional and ideational life now plays in the production of degeneracy, feeble-mindedness, insanity and anti-social behaviour of many sorts is understandable through analysis of the changes in man's physical, and social environment. Social stresses and economic strains and change of physical setting warp the behaviour of individuals, who are normal in mental make-up. Where society undergoes change at a rapid tempo or where the individual through rapid change of scene fails to establish affective linkages with his physical environment, misfits or failures are more frequent. On the other hand, the treatment of cases of insanity, crime and delinquency in hospitals and correctional institutions fully utilises the healing touch of Nature. The mental and emotional experiences derived from manual labour in fields and gardens are often found sound correctives of aberrations of abnormal personality and even provocatives of great achievements on their part. Similarly, it is being gradually recognised that through Nature-studies and Nature-activities, through

regional and occupational education, starting from their vital side and soon arriving at true technical skill, science and even art, we may readily have more of real and efficient educational reform as well as advance to social statesmanship. For thus may humanistic and mechanistic studies and activities be reconciled, absorbed and restated in terms of the essential concept of Life in Evolution, and this is as much essential for vital re-education as for social and regional reconstruction. Modern industrialism has created a breach not merely between the village and the city, but also between rural and urban standards of thought, between the physical sciences and their applications, on the one hand and the humanities on the other in the centres of learning. It is thus that a lack of balance between biological, physical and humanistic studies has accompanied the lack of ecologic balance between population, its activities and the region's resources in our present mechanical culture. Rural and regional thought and initiatives will now be found to be the most vital and comprehensive corrective of a civilisation, which in its desire for wealth and power has deprived man of many of Nature's own gifts and guarantees for his survival and development.

CHAPTER XVI.

THE ECOLOGICAL GOAL.

MAN, A PART OF THE ECOLOGICAL COMMUNITY OF LIFE.—The unit of social ecological study is the region which may be defined as an area throughout many dissimilar species of inhabitants adopt themselves to a common existence so that the ecological community as a whole persists. Man is a part of the organisation of life in the region, and his work and welfare to a large extent belong to the cycle of life processes of the region, where he competes with other living creatures for a place in the sun.

Man's success in adaptation and struggle between multitudes of different species in the region is expressed in terms of growth and density of his numbers.

Through the interplay of the ecologic forces of competition, invasion and succession, there is established a close correspondence between population, density, agriculture, food and the living and economic standards of a region. Man's adaptations include a control, an increased utilisation and an extension of the region. But in the long run the mode of social subsistence elicits and nourishes adaptive social institutions, standards of living and culture, imparting to the human community an unitary character.

As the result of the forces of competition and selection, human spatial and food relations conform to some definite and typical pattern, which represents the appropriate ecological distribution of human beings and activities in the region. Social organisation may be described in terms of the position, distribution and movements of individuals in space. Ecological area exhibits a more or less typical scheme of social gradation and hierarchy of values. The task of the individual is not merely to approximate the

status and plane of living of his group but to realise those ideal values which his station in life demands of him.

THE SPATIAL RELATIONS OF HUMAN GROUPS AND INDIVIDUALS.—Through competition, and the consequent specialisation and selection, every society is divided horizontally into several groups or strata, marked by social distance or segregation on the basis of community of occupation, income, standard of living or culture. The individual succeeds or fails to conform to the standard of his *milieu,* but it is the group which assures him an easy guidance in his adaptations. The human struggles and adaptations are less frequently for mere subsistence and more for position, status and power, and the individual falls in line with his group, which not only assures him subsistence and economic security but also gives him certain cultural devices and objectives. Both economic and cultural aims are subserved by each man's group adjustment, his location and power in one or other of the segregated social groups.

Through the processes of competition, specialisation and migration, every region comes similarly to be divided into certain specialised zones, such as forest, grazing, agricultural and manufacturing regions and centres of industry, trade and the liberal professions.

Each city or village in a region, again, shows segregations of populations on the basis of occupational interests, culture and living standards.

The forces of competition and selection operate to establish each class or caste which is an implement of man's cultural adjustment, or each ecological area forming the physical organisation of his economic exploitation in a definite relation to others, so that the social ecological frame-work presents an internal unity and coherence and develops a distinctive pattern.

According to the ecological order social divisions and distances thus become sometimes sharply defined, sometimes elastic. Thus individual talent, ambition and power,

not restricted in their social ambit, are disturbing factors, bridging social distances and removing the barriers of segregated groups. These seek to be registered in changes of location, and of economic and social status. The position of each individual in the social framework or of each natural area, occupation and industry in the ecological order, constantly shifts. Between the individuals, between the groups and between the natural areas, there are constant give and take, competition and co-operation, which establish an equilibrium, though a shifting one. The social-ecological plan or frame-work is the result of a continuous series of collective adjustments and individual tentative experiments. A significant change in any social group or ecological area or the achievement of a pioneer individual affects the functions and reciprocal relationships of every other in the ecological order.

In plant and animal communities "succession" is measured by the rate of change in the vital relationship among the units of the life-community. In human communities "cultural lag" is measured by the fixity of location, of social and economic status of individuals, a relatively fixed plane of living and social norm. A society undergoing rapid change is on the other hand characterised by rapid changes of occupation, of economic and social status and of location of individuals and change of social standards and ideals. The movement of population, a change in methods of production and in distribution of wealth, or new standards and ideals of living, which precede a new social gradation, all indicate a transformation of the ecological base and consequent transformation of the dynamic relations between the different parts of the life-community.

The cultural order is woven within the skeleton of the ecological order, and it is the intermeshing of the two orders, organic and spiritual, which sets before us the complex web of the whole life community in its completeness. As evolution progresses the organisation of life and mind in the region shows greater correlation and

solidarity, on the one hand, and extension and continuity on the other.

APPLIED ECOLOGY, THE ONLY GUARANTEE OF PERMANENT CIVILISATION.—Man can assure himself a stable dominance only by working in harmony with ecologic forces in different sections of the region, in the hills and mountains, in the slopes and in the level valleys, preserving Nature's protective cover of plants and plant roots and the appropriate quota of animals so as to keep the region suitable for human and animal habitation. As economic adaptation chalks out the region's natural orbit, forestry, pasturage, agriculture and manufacture must be made supplemental and complementary to one another in different parts of a region. A permanent form of agricultural and sylvicultural activity can furnish the only basis of a permanent civilisation, and this implies the conservation of the region, and of its intricate and fateful ecologic forces, which is far removed from the present lack of occupational balance, and manifold economic and social wastes. Economic equilibrium can be attained only if people and occupations in different levels of the valley section work harmoniously together for the uplift of the entire region. The supremacy of one or other of the succeeding stages or types of socio-economic life and organisation is bound to react unfavourably upon the progressive development of the region. In sectional economic planning resides the practical application of economic ecology.

The importation of new varieties of plants, animals and insects from similar habitats and adapted to particular ecologic purposes, has already opened out other new vistas for applied ecology. Modes of economic utilisation and social institutions may similarly be borrowed with profit from similar societies. Thus in the importation and crossing of plants, animals or social institutions, ecology points the way towards utilising the accumulated forces of the region for human use and welfare. Similarly, the problem of man's acclimatisation in new habitats or of competition of rival immigrant or native stocks in the same region, is rendered

easier of solution by more systematic ecological research than hitherto undertaken.

SOCIAL PATHOLOGY.—Man's asymbiotic multiplication and speedy use and disposal of nature's stores bring both himself and the region with its diverse species and grades of life to common ruin. Nature however has her safeguards in preserving a rhythm and balance of growth for all in the life-community in the increase of mortality and diminution of birth-rate as the density of numbers gets far beyond a limit which is locally desirable. Such measurable factors as the scarcity of food, the pressure of space, the multiplication of enemies, including parasites and the accumulation of organic waste products, bring about a decline of births and increase of mortality among animal populations that overstep an equilibrium density. In man also these automatic checks operate, and there is nothing immutable or obscure about the processes which are evident when a certain density of population is over-reached.

Not merely the decline of the survival rate but disease, whether of humans or of animals and plants, indicates a maladjustment to the region. Whether fungal and bacterial parasites in the case of plants and animals or pathogenic vegetable or animal organisms in the case of men, their dominance and spread are signals to the social ecologists. To the bio-ecologists disease is however far less significant than the decline of resistance of the organism, or lack of power to respond to changes in the environment. Both the morbidity of men and the decay of institutions are phenomena of social pathology. The differential mortality of people in different regions and under different occupations, for instance, clearly indicates how one stock or stage of economic development gives way to another. The study of the development of human communities reveals instances of the failure of adaptation of interacting men and of interrelated institutions to the environment; such phenomena are comparable with those of plant or animal suppression, disease and invasion.

SOCIOLOGICAL FORESIGHT.—Co-operation, scientific and broadminded, with the ecologic forces which have stamped the region with a unity and individuality ought to be the keynote of the future. The conservation of soil, water and food, the economy of man's food and energy circulation, the protection of the earth's mantle of trees and grasses, the selection and crossing of crops, trees and animals, the biological control or eradication of diseases, pests and parasites, the utilisation of all kinds of organic wastage, permanent agriculture, the conservation of water supply and the training and management of rivers and water-courses, a nicely adjusted occupational balance which may best utilize the resources and possibilities of different sections of the region and the skill and aptitudes of the people, all this is social ecology. Through the ages, as he has increased his numbers and his dominance, man has committed crime against sun and water, plants and animals, robbed in record time organisms and habitats that have been economically beneficial, introduced his own appurtenances in the way of domesticated animals and cultivated plants and disfigured the ground with the traces of his labours and devices, too often letting loose destructive forces which have impoverished and ultimately engulfed his civilisation even in the most favoured regions. Nature's processes of change are slow but sure. Man's quick methods of adjustment have often proved harmful in the long run, and enormous wastage of human toil and skill has followed in the wake of his startlingly rapid achievements. Man must to some extent imitate Nature's extraordinarily slow methods. In Nature the communities of life consisting of many different species found in a region are slow growths, but these are balanced and interlaced growths, selection being largely determined by the established system of linkages and correlations of organisms. The more surely does man adjust his own life to the processes and communities of life of his region, the more will he elicit Nature's enormous reserves of capital and energy for maintaining the continuity of himself and of his works, experiences and institutions in the region. Man's future advance lies, indeed, in a bio-economic co-operation,

based on the scientific comprehension of the complex web of Life that comprises both the Living and the Non-living realms and this is deeper than, and goes beyond, co-operation merely within the human community.

Such bio-ecologic co-operation is the pregnant and fateful lesson which the co-ordination of biological and social surveys yields for man's life and destiny in a given region.

Man's knowledge of the ecological web which is as yet scanty and partial must expand in order that he may be safe for the region and the region safe for him; and this will involve the re-orientation of the results of field workers as well as systematisers in such diverse specialised branches of learning as economics, agriculture, entomology, bio-chemistry and epidemiology. But mere scientific understanding of the web of life does not help matters. Man should cultivate a new humility and a new foresight in the interest of unborn societies of the future, which will be religious in its significance, before he can make himself the enduring and central link in the vital chain of food and energy circulation on the earth of which his pattern of civilisation is but a phase, and so far a passing one. The ecologic area or region forms the basic unit of all agricultural, economic and social plannings.

ECOLOGY AND SOCIAL PLANNING.—Neither the international nor national systems can work with proper efficiency, the organisations being too large and too mechanical to avail themselves of ecologic possibilities and local initiatives and patriotisms. The idea of territorial division and specialisation must now be focussed on ecologic areas and on sectional planning; the optimum units of production, whether farming or business units, as well as optimum production and optimum population should furnish the basis of a scientific human spatial distribution and economic distribution of occupation. Each ecological area, however, with its appropriate occupation balance and optimum production, is related to the larger territorial and national organisation, the functioning of which modifies and to a large extent regulates the

operations of a regional system. Areas of production of wheat and rice, sugar and tobacco, jute and cotton shift to new areas. Manufactures also shift, especially with developments in power and power transmission and with the mobility of labour. Regional planning should be governed by a careful study of cultural lag and inertia on the one hand, and of the persistence of internal forces and traditions associated with the ecological make-up of the region, on the other. The success of social planning would lie in reconciling the stabilisation and self-containedness of regional structures, controlled and made secure by a sort of 'regional mercantilism', with the economies of large scale technique, management and marketing crossing the boundaries of the regions. The balance between larger aggregates and economies of standardisation and regional autonomies and power, between the efficiency of the "great economy" and regional fitness and advantage, shifts. With such shifting are implicated new occupational balance and re-arrangement of industries, population and social groups, a new balance of work and leisure. An intersectional, balanced economy could be attained only as a result of co-ordinated and orderly regional and national planning, in which the constituent parts of the national economic order achieve co-operatively a programme of optimum production for the nation as a whole.

ECOLOGY AND WORLD ECONOMICS.—Applied ecology similarly shows the way to a better understanding and solution of inter-racial and inter-regional conflicts. Through the processes of competition, specialisation and migration, the earth is divided into economic regions, such as pioneer zones of forestry, mining and plantations, agricultural zones and zones of manufactures. Each zone of settlement presents its characteristic human space distribution, its distinct patterns of social composition, stratification and constitution. As in the plant world, the fringes of the different vegetation regions are ever being invaded by the surrounding vegetation, similarly the seeds of dominant civilisation move out to neighbouring regions and germinate. From the centres and foci of the old agricultural settlements peasant colonies spread out to the grass

lands, sand-dunes and forests; from the manufacturing zones, pioneer *entrepreneurs*, financiers and traders move out to mining and plantation zones for supplying their homelands with raw materials. Between the homeland and the new frontier of civilisation, there is a give and take of the human material as well, the homeland being used both as a reservoir for fresh supply of migrants and a refuge for those who fail in struggle and adaptation. The struggle and adaptation in the frontier zones are both climatic and social. The capacity for quick change of position in the spatial and occupational scheme and the capacity for quick acclimatisation mark out the successful migrant in the pioneer belts of settlement.

In the early stages of settlement, the pioneer invading stocks persist in a one-sided exploitation of the backward group or region and maintain superior political power and prestige as well as economic and social status, which cannot easily be challenged by the education, efficiency or ambitions of the backward groups. The social structure shows an unbalance like a pyramid standing on its apex where the dominating ethnic groups, numerically the fewest, are concentrated. In the intermediate stage the social structure of the settlement is characterised by spatial, communal and occupational segregation of the different ethnic groups, gradual levelling up of culture and efficiency and a constant upward pressure from the base of the occupation pyramid to the apex. In the last stage, the division of labour and social control patterns are governed entirely by the needs of conservation and development of the resources and inhabitants of the region; and ethnic groups and individuals keep changing positions and occupations until the different parts of the social structure approximate a symbiotic relationship maintained on the basis of the integrity and uplift of the ecologic order itself. Political power and economic prestige are shared by the superior and inferior groups; cultural distance is bridged; and the transition from a pioneer and backward zone of settlement to a mature zone with its modern technical and cultural equipment, distinctive of change of the ecological base, is accompanied

by an occupational and spatial redistribution and a new occupational balance, which conserves the resources of the region. The trend of interzonal ecologic co-operation on the earth is from a relationship based on a one-sided parasitism arising out of difference in levels of equipment and culture to one based on territorial division of labour in a uniform level of efficiency. Applied ecology thus lays bare the danger spots in human space distribution and exploitation of the earth, and in each new economic zone or frontier belt of civilisation points the way towards the establishment of the balance of population, occupation and culture, based on a symbiosis between the more efficient and immigrant and the backward resident groups, and the conservation and development of regional resources from the standpoint of its original or permanent residents rather than from that of the intrusive and immigrant non-residents. The physiological equipment, dietetic standard and incapacity for manual toil of the latter often make them less fitted, like exotic plants and animals inappropriate for ecologic aims, to profit best from the inheritance of the region. The present mal-distribution of world population and resources; the accompanying unbalance of agriculture, manufacturing and extractive industries; the social mal-adjustment and chaos characterised by the disparity of social status, prestige and power; and the capacity and desire for regional service of dominant cultural groups in many economic regions are the root causes of world misery in the midst of plenitude of resources. In no epoch in the history of human space distribution and exploitation of the earth, have a syneco-logical goal and programme been in more urgent and wide-spread demand than in the modern age with its economic nationalism splitting up the ecological unity of the earth, and its economic imperialism disintegrating the accumulated force of region and tradition.

ECOLOGY AND SOCIAL EXPERIMENTATION.—The problem of achieving a working balance of the world forces, and the balance of the nations and the regions in a new economy, is the supreme challenge for civilisation to-day. Applied ecology, integrating all the techniques and

mastery of the different social sciences, must take up this challenge and combat the vast cumulative disbalance by using the social engineering method of a series of schedules and projects, region by region, section by section, orientated and co-ordinated together in the context of a national and inter-regional scheme, yet spontaneous and flexible enough to overcome the friction and lag of a transitional economy. Only a realistic approach based on an inventory and appraisal of regional differences, capacities and possibilities, and experimentation rather than *a priori* assumptions and utopian plans, can succeed—and ecology is essentially a movement away from *a priorism,* artificiality and a set technology. Since the entire cultural order is implicated in the ecological order and succession, practical instrumentation will extend to comprehend not only the economic and political factors immediately involved, but also the institutional and cultural foundations of planning. It will proceed from the lower and basic level or rehabilitated balance of resources, technology and people, to the higher level of revivified social initiative and leadership, with the focus of action extending from the region to the state and from the state to the international organisation in widening contacts and complexified cultural inter-linkages.

Social ecological planning is an extremely delicate and sensitive art, embracing not only economics but also legislation, public administration and education in different levels and systems of organisation. Man has brought irreparable damage upon the region and upon himself by his ignorance of, and awkward interference with, the established system of inter-relations in nature. The system of inter-relations in the social order which is interwoven within the frame of the ecological order is much more subtle, intimate and sentitive. Social planning no doubt is the inevitable goal of ecology and civilisation, but an unintelligent meddling with social trends and relations will be much more disastrous than interference with reference to the affairs of nature. Ancient *laissez faire* notions will perpetuate social chaos and misery and imply the bank-

ruptcy of the social sciences. On the other hand, as the patterns of social order and relations have become more and more delicately and intimately interwoven, the dangers of misplanning have become far greater and more far-reaching in their consequences.

THE PATTERN OF LIVING, A PROGRESSIVE SERIES OF WHOLES AND OF SUBTLE INTER-RELATIONS.—Briefly speaking, the influence of the region on the whole life community and of the life community on the region expresses the maintenance of specific normal pattern and activity. In ecology, plant, animal or human, we never get away from the specific pattern of life. The conception of a specific normal pattern of life and its maintenance is here fundamental, whether we are considering the inter-relations of great harmonic vegetable or animal aggregations which have arrived at a more or less stable equilibrium in the region, or the inter-linkages of economic, social or political arrangements. The pattern of life is an actively maintained whole, at first confined to, but later transcending, the the boundaries of time and space, and both the structure and life activities of its component communities, subhuman and human, are manifestations of this organic unity.

The presence or absence of a single factor thus changes the whole pattern of life from non-living to living and cultural levels. To give an instance, the acidity of the soil, the deficiency of iodine, calcium or other mineral elements, or the presence of some single parasite or an important species, will change the nature and succession of vegetation and animal life of the region, and, through the man's cultivation and industries, his character, interests and habits and the lines on which his civilisation develops. Thus the conception of the pattern of life applies indefinitely beyond the immediate environment of any of the species of inhabitants within the region, and extends to the structure and activities of the entire ecological community, including both the biological and cultural series. The pattern of life, fashioned first by the physical and chemical characters of the environment, shows a specific co-ordinated unity of structure and activity, also, in its

radiations and extensions in the spheres of culture and tradition. It grows and evolves as a whole, bringing about a harmony of the lesser and simpler with a greater and more complex whole of Nature. In the subtle ways of Nature, sunshine and rain, land and stream, plants and animals mingle silently with mind, society and culture and become part of their structure. The region and the life-community the larger national and international systems in their reciprocal give and take, record the gradual, development of progressive series of wholes, stretching from the inorganic beginnings to the highest levels of spiritual creation, from regionalism and nationhood to cosmic humanism. We thus reach by another line of reasoning Smuts' conception of Holism. "The creative intensified Field of Nature, consisting of all physical, organic and personal wholes in their close interactions and mutual influences, is itself of an organic or holistic character,—that Field is the source of the grand Ecology of the Universe. It is the environment, the Society—vital, friendly, educative, creature of all wholes and all souls." The trend of evolution, which ecology envisages, is for the pattern of life to attain greater and greater solidarity and permanence through friendly, intimate and subtle linkages. What is organic in Nature and shapes her ends blindly and haphazardly becomes purposive in human society, and thus the pattern of life, spiritually and teleologically progressive, crosses the boundaries of time and space. Bio-ecologic co-operation or, to use another term, symbiosis, organic and social, is the key to the permanence of man's civilisation, his works and experiences on the earth. May not this be a faint glimpse of that majestic symbiosis of the Universe brought about by the harmony of the varied forces of Nature, of gravitation, light, time, the unseen rays or the sidereal influences, which has woven for man's vision through the ages the synoptic conception of Absolute Truth, Beauty and Goodness?

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